NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

RIGHT TECHNOLOGY, RIGHT NOW: AN EVALUATION METHODOLOGY FOR RAPIDLY DEPLOYABLE INFORMATION AND COMMUNICATIONS TECHNOLOGIES IN HUMANITARIAN ASSISTANCE/ DISASTER RELIEF

by

James Gregory Gabriel

March 2012

Thesis Co-Advisors: Brian Steckler
Gurminder Singh

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202–4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704–0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2012	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Right Technology, Right Now: An Evaluation Methodology for Rapidly Deployable Information and Communications Technologies in Humanitarian Assistance/Disaster Relief			**5. FUNDING NUMBERS**
6. AUTHOR(S) James Gregory Gabriel			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943–5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ______N/A______.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The most significant technological challenge after a major humanitarian disaster is the rapid deployment of information and communications technologies (ICT) for initial responders. Reliance on ICT—particularly wireless communications—is essential to a coordinated response, particularly in international disasters due to the large number and diversity of responding organizations. Therefore, choosing the most effective ICT systems for disaster response is a critical factor for ensuring success of the response effort. This research will provide background information related to selecting rapidly deployable ICT resources for disaster responders by exploring U.S. policy, worldwide disaster trends, and U.S. government responses. In addition, this thesis will evaluate ICT challenges that are unique to the post-disaster environment and identify essential characteristics of rapidly deployable ICT systems. Finally, this research will develop a quantifiable methodology based on essential characteristics to evaluate and compare commercially-available ICT systems in order to identify systems best suited for the disaster environment. Revelations will contribute to potential policy recommendations and follow-on research that will facilitate determination of the best ICT options, resulting in more effective cooperative utilization of these technologies to improve post-disaster responsiveness.

14. SUBJECT TERMS humanitarian assistance, disaster relief, information and communications technology, hastily formed networks, wireless communications			**15. NUMBER OF PAGES** 107
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01–280–5500

Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

RIGHT TECHNOLOGY, RIGHT NOW: AN EVALUATION METHODOLOGY FOR RAPIDLY DEPLOYABLE INFORMATION AND COMMUNICATIONS TECHNOLOGIES IN HUMANITARIAN ASSISTANCE/DISASTER RELIEF

James Gregory Gabriel
Lieutenant, United States Navy
B.B.A., University of Georgia, 2002

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 2012

Author: James Gregory Gabriel

Approved by: Brian Steckler
Thesis Co-Advisor

Gurminder Singh
Thesis Co-Advisor

Dan Boger
Chair, Department of Information Sciences

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The most significant technological challenge after a major humanitarian disaster is the rapid deployment of information and communications technologies (ICT) for initial responders. Reliance on ICT—particularly wireless communications—is essential to a coordinated response, particularly in international disasters due to the large number and diversity of responding organizations. Therefore, choosing the most effective ICT systems for disaster response is a critical factor for ensuring success of the response effort. This research will provide background information related to selecting rapidly deployable ICT resources for disaster responders by exploring U.S. policy, worldwide disaster trends, and U.S. government responses. In addition, this thesis will evaluate ICT challenges that are unique to the post-disaster environment and identify essential characteristics of rapidly deployable ICT systems. Finally, this research will develop a quantifiable methodology based on essential characteristics to evaluate and compare commercially-available ICT systems in order to identify systems best suited for the disaster environment. Revelations will contribute to potential policy recommendations and follow-on research that will facilitate determination of the best ICT options, resulting in more effective cooperative utilization of these technologies to improve post-disaster responsiveness.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

3G	3rd Generation
ANSI	American National Standards Institute
ASD (NII)	Assistant Secretary of Defense for Networks and Information Integration
BGAN	Broadband Global Area Network
C2	Command and Control
CHSC	California Homeland Security Consortium
CIE	Collaborative Information Environment
CJCS	Chairman of the Joint Chiefs of Staff
DoD	Department of Defense
DoD CIO	Department of Defense Chief Information Officer
DR	Disaster Relief
Gbps	Gigabits per Second
GHz	Gigahertz
GIS	Geographical Information System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HA	Humanitarian Assistance
HFN	Hastily Formed Network
ICT	Information and Communications Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IP Code	Ingress Protection Code (from IEC 60529)
IPC3	Independently Powered, Command, Control, and Communications
ISDN	Integrated Services Digital Network
JP	Joint Publication
kbps	Kilobits per Second
MANET	Mobile Ad-Hoc Networking
Mbps	Megabits per Second

MHz	Megahertz
MSS	Mobile Satellite System
NEMA	National Electrical Manufacturers Association
NGO	Non-Governmental Organization
NPS	Naval Postgraduate School
PACOM	United States Pacific Command
PDA	Personal Digital Assistant
POE	Power Over Ethernet
RFID	Radio Frequency Identification
SatCom	Satellite Communications
SecDef	Secretary of Defense
SMS	Short Message Service
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP	User Datagram Protocol
UN	United Nations
UNESCAP	UN Economic and Social Commission for Asia and the Pacific
USAID	U.S. Agency for International Development
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WEP	Wired Equivalent Privacy
Wi-Fi	IEEE 802.11 standard (sometimes referred to as wireless fidelity)
WiMAX	Worldwide Interoperability for Microwave Access (IEEE 802.16)
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WPA	Wi-Fi Protected Access
WVoIP	Wireless Voice over Internet Protocol

I. INTRODUCTION

A. BACKGROUND

Natural disasters can inflict severe damage to telecommunication infrastructures leading to the loss of critical voice and data services, thereby limiting efficient emergency response and causing delays contributing to loss of life (Ring, Foo, & Looi, 2007). Consequently, one of the most significant technological challenges after a humanitarian disaster is the rapid deployment of information and communications technologies (ICT) for initial disaster relief responders. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) noted, "it is widely recognized that ICT, including space-based technology, plays an important role in establishing early warning systems and successfully conducting preparedness and response activities" (2009, p. 1). Reliance on ICT—particularly wireless data communications—is essential to a coordinated response among the various agencies and organizations in both domestic and foreign disasters. In international disaster scenarios, communications have an even greater impact on relief efforts due to the larger number and diverse types of responding organizations (e.g., multiple foreign and domestic government agencies, non-governmental organizations [NGOs], international organizations [IOs], private industry, and academia). Therefore, choosing the best and most effective ICT systems for use during disaster response missions is vital to ensuring the overall success of response efforts.

B. OBJECTIVES

Frassl et al. noted in 2010 that "integrated systems to support disaster relief operations in the field have only recently attracted significant interest in the civil protection and scientific communities…the knowledge base in terms of specific system requirements is still thin" (Frassl, Lichtenstern, Khider, & Angermann, p. 2). This research will expand this knowledge base by providing insights into the opportunities and challenges related to selecting rapidly deployable ICT resources for humanitarian disaster responders by exploring U.S. policy, worldwide disaster trends, and responses by the

U.S. government. In addition, this thesis will explore ICT challenges that are unique to the disaster environment and commonly-used technologies in order to determine essential characteristics of rapidly deployable ICT systems that are most appropriate for supporting the response phase of a humanitarian disaster. Finally, this research will develop a quantifiable methodology based on identified essential characteristics that will enable decision makers to evaluate and compare rapidly deployable ICT systems from commercial providers to identify systems that are best suited for humanitarian missions. Revelations will contribute to potential policy recommendations and follow-on research that will facilitate determination of the best technologies appropriate for humanitarian operations, resulting in more effective cooperative utilization of these technologies to improve post-disaster responsiveness.

This research is also motivated by Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer (ASD (NII)/DoD CIO) guidance to identify:

> Communications requirements for stabilization and reconstruction, disaster relief, and humanitarian and civic assistance among the DoD Components, U.S. departments and agencies, foreign governments and security forces, IOs, NGOs, and members of the private sector involved in stabilization and reconstruction, disaster relief, and humanitarian and civic assistance. (2009, p. 9)

C. SCOPE

1. Defining Humanitarian Assistance and Disaster Relief

The Chairman of the Joint Chiefs of Staff (CJCS) has defined humanitarian assistance (HA) and foreign disaster relief (DR) in Joint Publication (JP) 1–02, as referenced in Table 1.

Table 1. Definitions for HA/DR (From Chairman of the Joint Chiefs of Staff [CJCS], 2010)

Humanitarian Assistance	"Programs conducted to relieve or reduce the results of natural or manmade disasters or other endemic conditions such as human pain, disease, hunger, or privation that might present a serious threat to life or that can result in great damage to or loss of property. Humanitarian assistance provided by U.S. forces is limited in scope and duration. The assistance provided is designed to supplement or complement the efforts of the host nation civil authorities or agencies that may have the primary responsibility for providing humanitarian assistance" (p. 156).
Foreign Disaster Relief	"Prompt aid that can be used to alleviate the suffering of foreign disaster victims. Normally it includes humanitarian services and transportation; the provision of food, clothing, medicine, beds, and bedding; temporary shelter and housing; the furnishing of medical materiel and medical and technical personnel; and making repairs to essential services" (p. 133).

In order to promote clarity and understanding across organizations—public and private—with shared interests in humanitarian operations, "HA/DR" will be the common terminology used throughout this thesis to identify the overarching missions and concepts identified in Table 1.

2. Disaster Management Phases

The management of disasters at all levels of government—local, state, national, and international—can be best described as occurring in four phases: prevention, preparedness, response, and rehabilitation (World Health Organization [WHO], 2002). Although all four phases shown in Figure 1 are interrelated and equally important to addressing a disaster's destructive effects, this thesis will focus primarily on the response phase and the corresponding goals of protecting the population, limiting the damage from the primary event, and minimizing damage from potential secondary impacts (Lindell, Prater, & Perry, 2007). In order to best contribute to the response effort, the essential characteristics of ICT systems, as well as the evaluation of selected systems, will emphasize rapid deployability to worldwide locations under harsh conditions.

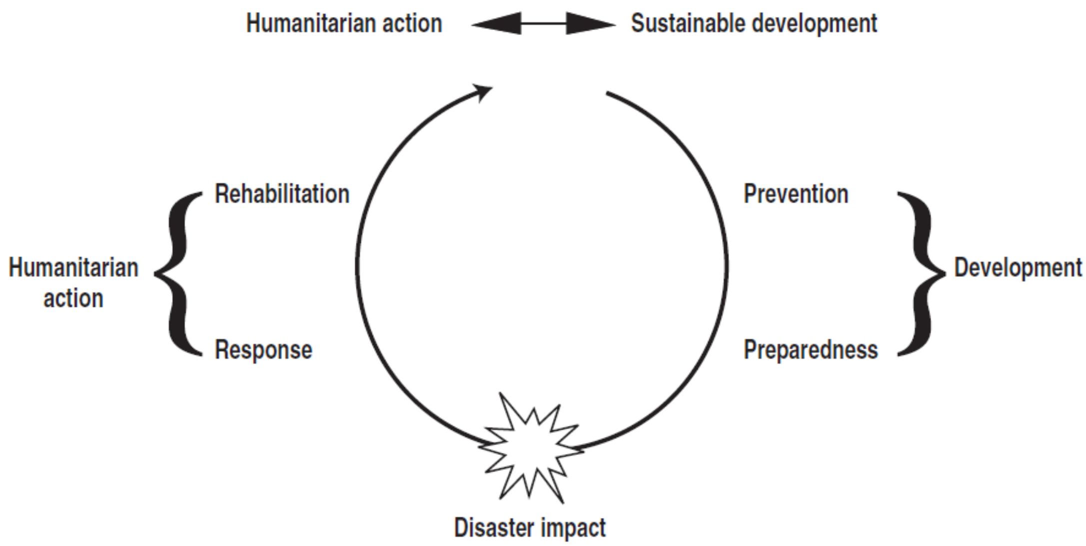


Figure 1. Disaster Management Cycle (From WHO, 2002, p. 3)

3. Disaster Types

Disasters are classified based on their immediate triggers and can be described as:

- Natural disasters caused by a natural phenomenon or hazard;
- Technological disasters caused by a technological or industrial accident;
- Complex emergencies caused by warfare, civil disturbance, or large-scale movements of people.

Natural disasters are further defined as either sudden or slow onset. Sudden onset disasters, which include geological (earthquake, tsunami, volcanic eruption), climactic (flash flood, hurricane, typhoon), and biological (major epidemic) events, have the greatest impact on the deployment and utilization of data and information management systems (Amin & Goldstein, 2008). Consequently, this thesis will focus on sudden onset natural disasters due to the difficulties they can present when selecting ICT resources.

4. Communication Challenges

A principal obstacle in responding to both naturally-occurring and man-made disasters is the ability to communicate. This has been evident across recent disasters such

as Hurricane Katrina in 2005, Cyclone Nargis in 2008, and the 2010 earthquake in Haiti. Communication challenges can include further be divided into three categories: technological, sociological, and organizational (Manoj & Baker, 2007). This thesis will focus on the technological aspects of communications following a disaster. Further, Nelson, Steckler, and Stamberger (2011) indicated "responders are budget-constrained, making it is critical that communications equipment be easily obtained off-the-shelf instead of military equipment that can be expensive and hard to obtain" (p. 468). Therefore, the evaluated technologies and systems will all be commercially-available products so this research can potentially benefit a broad range of organizations.

D. POTENTIAL BENEFITS, LIMITATIONS, AND RECOMMENDATIONS

Wentz (2006) argued that ICT is essential to:

> The coordination mechanisms that civilian and military organizations need to assist local populations and host governments … capabilities and requirements need to be better understood, so that relief and reconstruction efforts can be better constructed and coordinated by all parties working in the interest of the affected population. (p. 1)

Therefore, a key benefit of this research will be to better understand the capabilities and requirements of ICT by determining essential characteristics and developing evaluation criteria for rapidly deployable ICT systems that could be utilized in an HA/DR environment. Due to resource and time limitations, only six commercial products will be evaluated representing three different data communications requirements. Potential recommendations may support desired features for future systems, use of prioritized feature criteria for other mission areas (i.e., traditional military applications), and evaluations of other comparable systems to validate the results of systems testing and evaluation criteria.

E. CHAPTER OUTLINE

Thesis research, evaluation criteria, and findings will be organized in the following manner:

- Chapter I, Introduction: Provide a general outline and scope of the work performed and define areas the thesis research intends to address.
- Chapter II, Background: Discuss HA/DR policy, trends, and efforts with respect to the U.S. government. Provide a foundation for ICT, including the importance of ICT to successful HA/DR operations, and discuss the most common commercially-available ICT systems such as satellite-based Internet connections and wireless networking standards.
- Chapter III, System Characteristics and Evaluation Methodology: Identify essential characteristics of rapidly deployable ICT systems that would be most important for effective disaster response. Discuss methodology used to evaluate and quantitatively compare ICT systems based on meeting essential characteristics.
- Chapter IV, Commercial Systems Overview and Testing: Using the previously identified characteristics and methodologies, describe and evaluate rapidly six deployable commercial ICT systems.
- Chapter V, Conclusions and Future Work: Analyze the results of the commercial systems testing in order to provide conclusions, recommendations, and areas for follow-on research.

II. BACKGROUND

A. HA/DR POLICY, TRENDS, AND MISSIONS

In order to fully appreciate the requirements and challenges associated with deploying and utilizing ICT in the HA/DR environment, it is prudent to first consider U.S. government and Department of Defense (DoD) policy regarding HA/DR and recent disaster trends eliciting responses from the U.S. and the international community.

1. Policy

Over the past several years, the U.S. government—particularly DoD—has emphasized the importance of maintaining a robust HA/DR capability. Efforts have been evident at all levels of government and observed in strategic policies emphasized by principle decision makers. For example, President Barack Obama's *National Security Strategy* (2010) indicated that:

> Together with the American people and the international community, we will continue to respond to humanitarian crises to ensure that those in need have the protection and assistance they need…the United States must be better prepared and resourced to exercise robust leadership to help meet critical humanitarian needs. (pp. 39–40)

From a DoD perspective, *The National Military Strategy of the United States of America: Redefining America's Military Leadership* (2011) identified strengthening international and regional security, which includes HA/DR, as one of four national military objectives. CJCS Admiral Mike Mullen, when describing HA/DR as a component of this key strategic objective, directed that:

> We must plan and exercise extensively across Combatant Commanders' seams of responsibility for full spectrum contingencies to support U.S. diplomatic and development efforts and help mitigate and contain the human and economic impact of crises. Humanitarian assistance and disaster relief activities employ the Joint Force to address partner needs and sometimes provide opportunities to build confidence and trust between erstwhile adversaries. They also help us gain and maintain access and relationships that support our broader national interests. We must be prepared to support and facilitate the response of the United States Agency

> for International Development [USAID] and other U.S. government agencies' to humanitarian crises. (2011, p. 15)

Additionally, in the recently published DoD strategic guidance *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense*, Secretary of Defense (SecDef) Leon Panetta (2012) reaffirmed the role of "humanitarian, disaster relief, and other operations" as "primary missions of the U.S. Armed Forces," in which he emphasized (pp. 4–6):

> The nation has frequently called upon its Armed Forces to respond to a range of situations that threaten the safety and well-being of its citizens and those of other countries. U.S. forces possess rapidly deployable capabilities, including airlift and sealift, surveillance, medical evacuation and care, and communications that can be invaluable in supplementing lead relief agencies, by extending aid to victims of natural or man-made disasters, both at home and abroad. DoD will continue to develop joint doctrine and military response options to prevent and, if necessary, respond to mass atrocities. (p. 6)

With regard to the maritime domain, the U.S. Navy, U.S. Marine Corps, and U.S. Coast Guard have equally emphasized the importance of maintaining and further developing a worldwide, robust HA/DR capability. *A Cooperative Strategy for 21st Century Seapower* (2007) identified HA/DR as one of only six primary capabilities that comprise "the core of U.S. maritime power and reflect an increase in emphasis on those activities that prevent war and build partnerships" (Conway, Roughead, & Allan, pp. 12–14).

2. Trends

Multiple studies (Amin & Goldstein, 2008; UNESCAP, 2009; Munich RE, 2011; Bensahe & Cronin, 2012) have indicated increasing frequency and severity of humanitarian disasters over recent decades. Members of the global insurance and risk management industry, such as the German firm Munich RE, have developed "geointelligence" through the use of statistical analysis of natural catastrophes, historical loss data, and global hazard maps in order to develop information on risk locations, estimates of the loss potentials from natural hazards, and historical trends as depicted in Figure 2 (Munich RE, 2012).

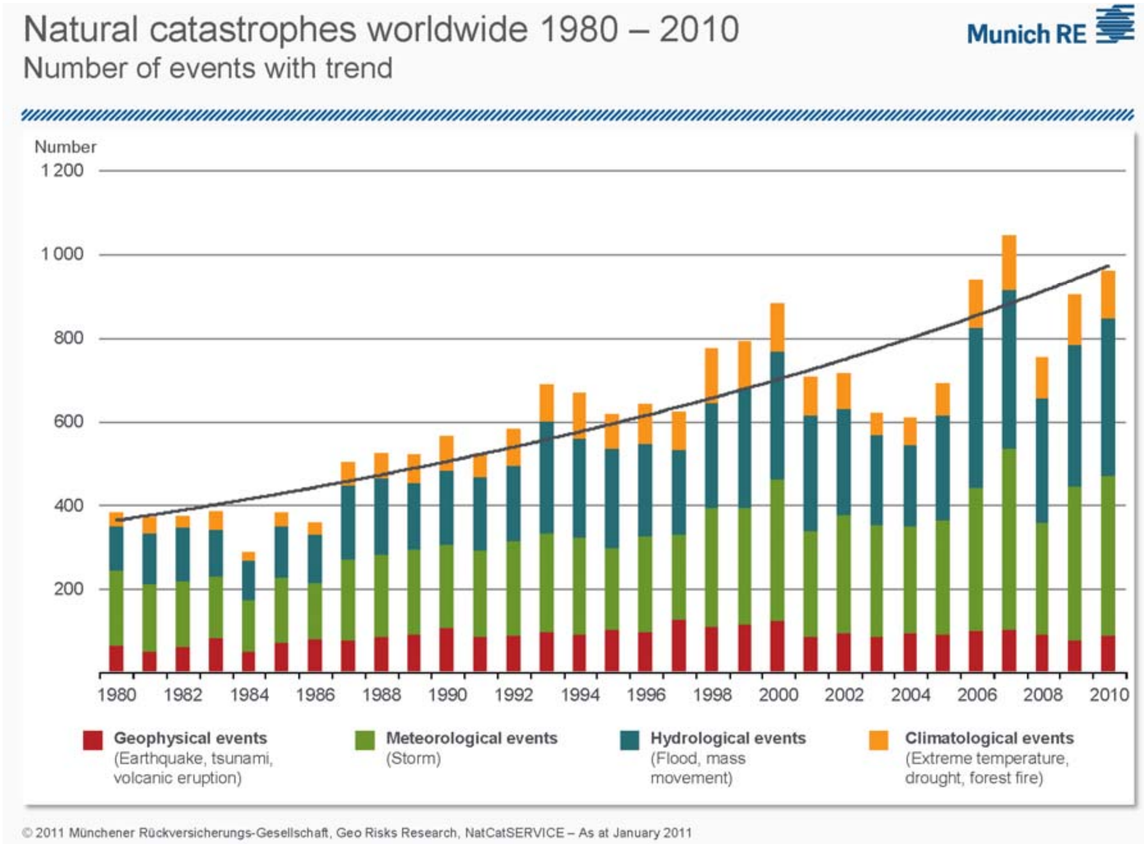


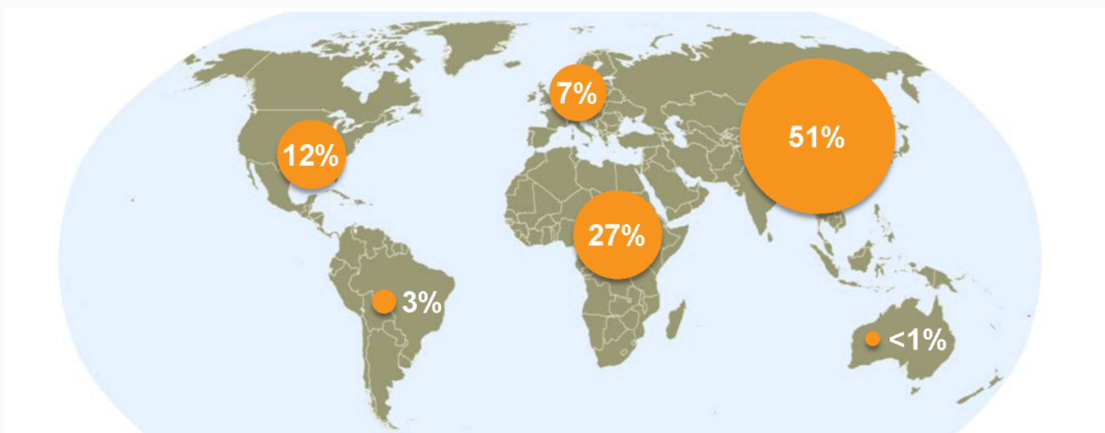
Figure 2. Worldwide Natural Disasters from 1980–2010 (From Munich RE, 2011)

In addition to indicators that the quantity and severity of disasters are increasing, long-term trends also provide historical insight into the populations and locations most impacted by natural catastrophes due to the strong relationship between poverty and vulnerability to natural disaster. Amin and Goldstein (2008) referenced a study identifying, “while only 11 percent of the people exposed to natural hazards live in countries classified as low human development, they account for more than 53 percent of the total recorded deaths” (p. 23). Although nearly all countries are at-risk of natural hazards, Amin and Goldstein (2008) also indicated that, out of 47 countries with more than 50 percent of their population at relatively high mortality risk from at least two natural hazards, only Japan, South Korea, and Taiwan were considered developed (p. 25). Analysis from Munich RE concurs with this data, pointing to Asia and Africa as having the greatest distribution of fatalities since 1980, as shown in Figure 3.

Natural catastrophes 1980 – 2010

2,275,000 Fatalities - Percentage distribution per continent

Munich RE



Continent	Number of Events	Fatalities	Overall losses* [US$ m]	Insured losses* [US$ m]
Africa	1,700	607,000	43,000	2,000
America (North and South America)	5,900	362,000	1,265,000	496,000
Asia	6,200	1,150,000	1,150,000	66,000
Australia/Oceania	1,470	5,620	77,000	23,000
Europe	4,100	150,000	485,000	148,000

Figure 3. Fatalities Caused by Natural Disasters from 1980–2010 (From Munich RE, 2011)

Recent data has also indicated that 2010 was a particularly difficult year for natural disasters worldwide, with 960 loss events, as depicted in Figure 4.

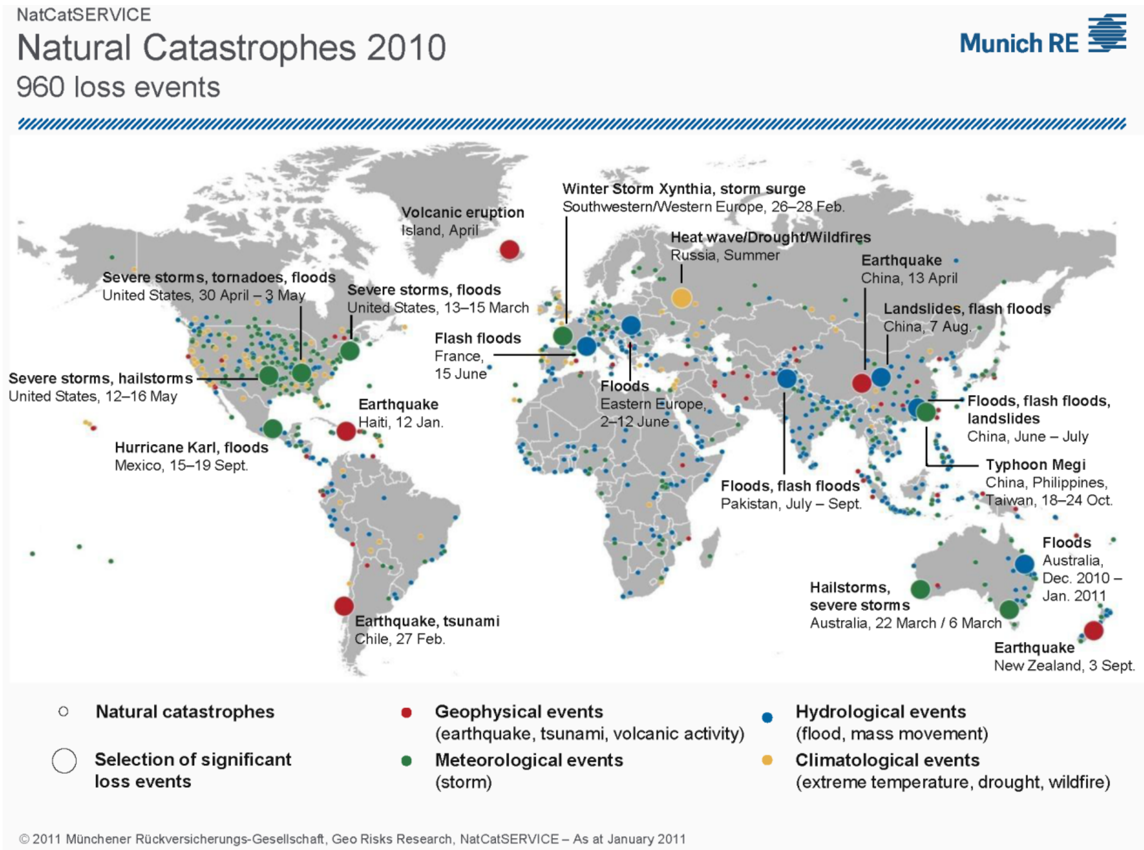


Figure 4. Natural Disasters from 2010 (From Munich RE, 2011)

As presented in Figure 5, losses in terms of fatalities/injuries, destruction of property, and recovery costs were excessive, predominantly due to major events in Haiti, Chile, China, and New Zealand during 2010.

Loss figures

Earthquake in Haiti, 12 January	
Fatalities	222,570
Injured	310,000
Number of homes destroyed/damaged	285,000
Overall loss (US$ m)	8,000
Insured loss (US$ m)	200

The quake on 12 January 2010 ranked second in the list of deadliest earthquakes since 1950. More lives were claimed only by the 1976 Tangshan quake in China.

Loss figures

Earthquake in Chile, 27 February	
Fatalities	>520
Injured	12,000
Number of homes destroyed/damaged	370,000
Overall loss (US$ m)	30,000
Insured loss (US$ m)	8,000

For the Chilean insurance industry, the Maule quake was the most expensive earthquake ever. In global terms, only the 1994 Northridge quake in the USA caused a higher insured loss.

Loss figures

Earthquake in China, 13 April	
Fatalities	2,700
Injured	12,100
Number of homes destroyed/damaged	15,000
Overall loss (US$ m)	500
Insured loss (US$ m)	–

Due to the number of earthquakes in 2010, the Chinese earthquake paled in significance although it ranked sixth in the list of deadliest quakes in China since 1950.

Loss figures

Earthquake in New Zealand, 3 September	
Fatalities	–
Injured	2
Overall loss (US$ m)	6,500
Insured loss (US$ m)	5,000

For New Zealand's insurance industry, the Christchurch earthquake proved to be the costliest natural catastrophe in the country's history. In a worldwide comparison of insured losses, it was the second costliest of the year 2010.

Figure 5. Major Natural Disasters in 2010 (From Munich RE, 2011)

3. Missions

Although the primary purpose of the U.S. military is to ensure the national security of the United States, DoD's contribution to HA/DR cannot be understated. According to the *Naval Operations Concept 2010: Implementing the Maritime Strategy*, U.S. military forces were involved in 22 combat-related missions from 1970–2000; however, the armed services responded to 366 HA/DR missions over this same period—over 11 times more that combat-related missions. Specifically, forces from the U.S. Navy have responded to numerous major events in recent years, some of which included:

- 2004: Indian Ocean earthquake and tsunami;
- 2005: Hurricane Katrina on the U.S. Gulf Coast and Pakistan earthquake;
- 2006: Mudslide on the Island of Leyte;
- 2007: Hurricane Felix in Nicaragua and Cyclone Sidr in Bangladesh;
- 2008: Typhoon Fengshen in the Philippines;
- 2010: Haiti earthquake (Conway, Roughead, & Allan, 2010).

Other U.S. government entities beyond DoD have also responded extensively to HA/DR events in recent decades. Civilian government agencies led by the State Department and USAID have conducted hundreds of operations to deliver humanitarian assistance in response to natural disasters as depicted in Figure 6 (Bensahe & Cronin, 2012).

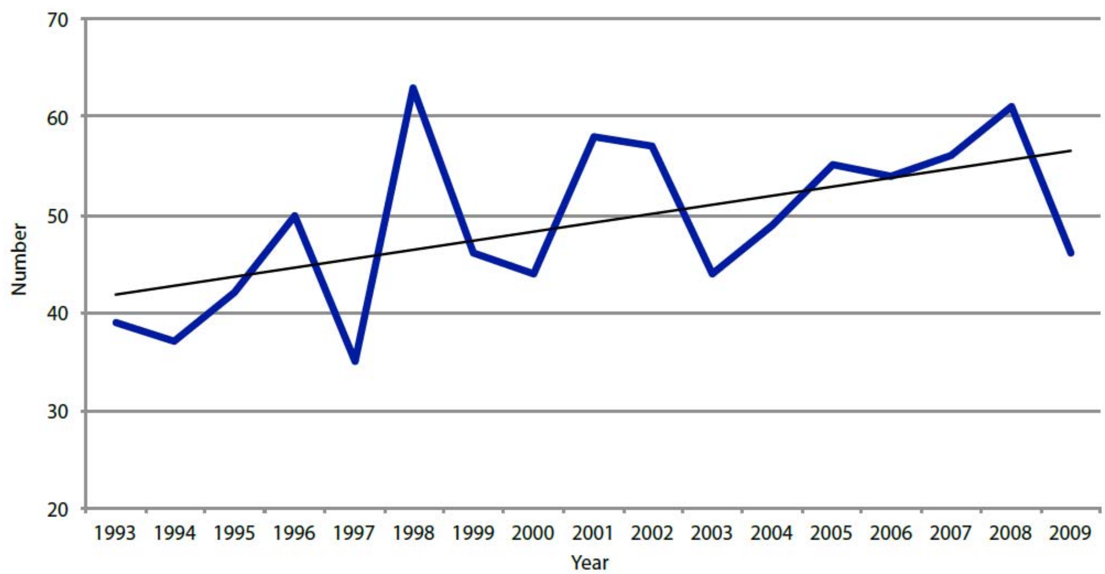


Figure 6. Annual Civilian U.S. Government Agency HA/DR Missions, 1993–2009 (From Bensahe & Cronin, 2012)

On average, civilian agencies have conducted 49 HA/DR missions each year from 1993–2009, varying from a low of 35 in 1997 to a high of 63 in 1998. Additionally, as shown in Figure 7, these missions were predominantly in response to rapid onset natural disasters such as floods, earthquakes, and storms. (Bensahe & Cronin, 2012).

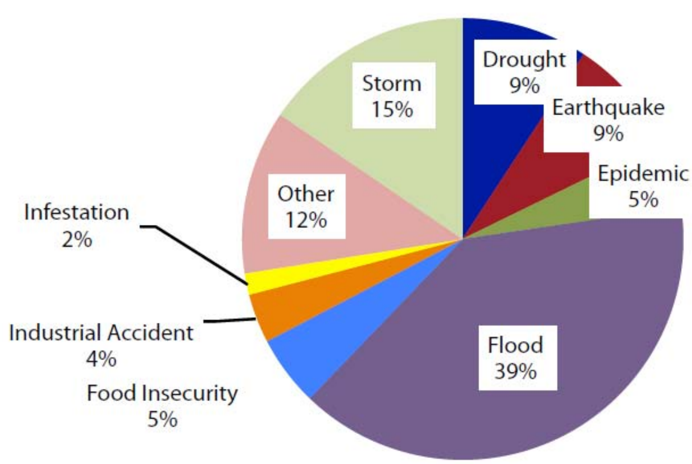


Figure 7. Categories of Civilian U.S. Government Agency HA/DR Missions, 1993–2009 (From Bensahe & Cronin, 2012)

As a result of the numerous recent disaster events, DoD and U.S. government civilian agencies have become increasingly interested in the successes, challenges, and lessons learned associated with responding to disasters, particularly with respect to the means for improving coordination and information sharing among responders—regardless of agency (Christman, Kramer, Starr, & Wentz, 2006).

B. SIGNIFICANCE OF ICT TO HA/DR OPERATIONS

ICT systems and the flow of information across the wide-range of responders are vital to the HA/DR effort; however, the use of these technologies faces numerous challenges not encountered in typical communications or information applications.

1. ICT Overview

ICT is an extremely broad terminology used primarily by the international community to convey the combination of technologies that manage the overarching flow of information and enable voice and data communication through both wired and wireless media. In DoD terms, ICT includes:

> Information systems and communications equipment, primarily commercial-off-the-shelf based, that have been purchased by DoD Components to supplement command and control systems and DoD business process systems; in particular, those that facilitate coordination and cooperation with non-DoD entities…[possibly] used in a stay-behind equipment pool for non-DoD entities. (ASD[NII]/DoD CIO, 2009, p. 12)

In an HA/DR environment, primary functions supported by ICT include:

- Emergency response capability;
- Communication and dissemination;
- Information collection and sharing;
- Integration, monitoring, and warning (UNESCAP, 2009).

2. Importance of Communications and Information

Effective communications are essential to all phases of successful HA/DR operations. Specifically, from a military perspective, communications interconnect all

aspects of joint operations, while ensuring commanders maintain command and control (C2) of their forces. CJCS guidance in *JP 3–29: Foreign Humanitarian Assistance* directs that HA/DR plans "must include procedures to provide interoperable and compatible communications among participants," utilize commercial ICT systems "to coordinate with other U.S. agencies, disseminate meeting schedules, deconflict resource movement, and track logistic flow," and establish communications with NGOs "to facilitate effective collaboration and decision-making" (CJCS, 2009, p. IV-4).

From an overarching perspective, Christman et al. (2006) indicated that the sharing of information is particularly critical following a disaster "because no single responding entity can be the source of all of the necessary information" (p. 3). As a result, making critical information widely available to the various responding entities identified in Figure 8 "not only reduces duplication of effort, but also enhances coordination and provides a common knowledge base so critical information can be pooled, analyzed, compared, contrasted, validated, and reconciled" (Christman, Kramer, Starr, & Wentz, 2006, p. 3).

Figure 8. Typical Organizations Involved in HA/DR Missions

Disaster communication capacities are not only critical for timely dissemination of early warnings of approaching hazards and immediate reporting of disaster occurrence, but are also essential for effective organizing and coordinating response actions following a disaster as depicted in Figure 9 (UNESCAP, 2010).

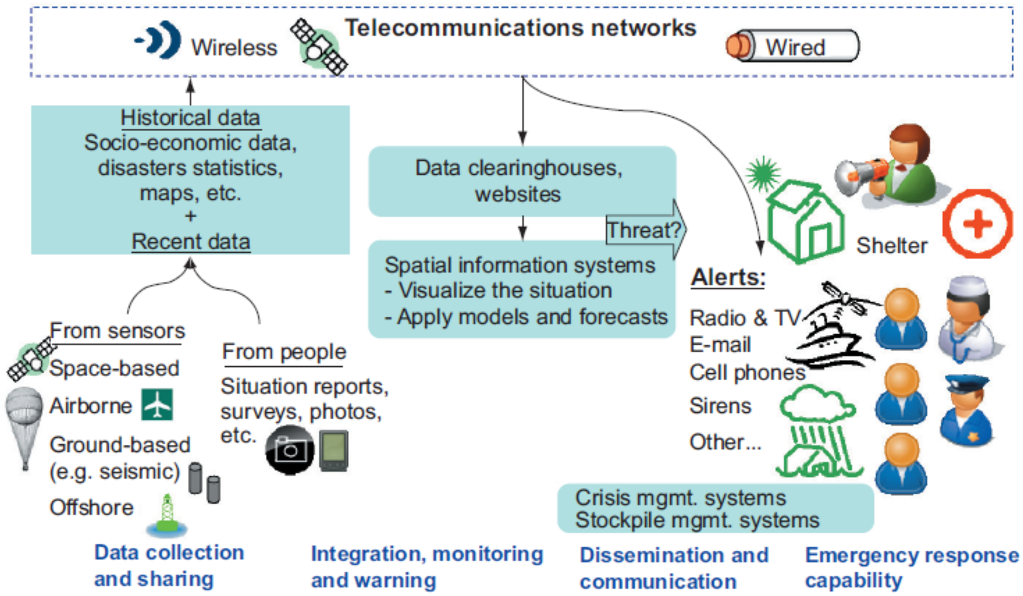


Figure 9. Example of Integrated ICT System (After UNESCAP, 2009)

UNESCAP (2010) noted that reliable sharing of information is critical during the response phase of an HA/DR mission to ensure the right information from all relevant sources is transmitted to the right entities—particularly decision makers and the affected communities. The group's report identified the types of information communicated during the response phase of major disasters, including:

- Locations, affected areas, and preliminary assessments of disaster impacts;
- Information flow between agencies regarding the severity of the disasters, response plans, and coordination of response actions, including field-accessible background information from various information systems about the affected areas;
- Monitoring and early warning of secondary disasters such as structure collapses, flooding, aftershocks, landslides, and wildfires;

- Communications among responders regarding judicious organization, coordination, and deployment for operations related to mitigation, rescue, and relief (UNESCAP, 2010, pp. 3–4).

3. Technological Challenges

Following a large-scale disaster, the majority of previously available voice and data communications capabilities are likely to have been degraded and/or destroyed. This significantly impacts the overall success of the response effort due to the limited ability of responders to effectively communicate. Ring et al. (2007) have identified five ways in which a destructive event can affect preexisting communications capabilities as described in Table 2.

Table 2. Vulnerabilities of Mobile Technologies (From Ring et al., 2007)

Vulnerability	Description
Destruction of Infrastructure	An example of this was in the 9/11 terrorist attacks on the World Trade Center where a large portion of the GSM switching equipment servicing lower Manhattan was located in the twin towers. Therefore, the terrorist attack had the impact of causing a mass outage of mobile communication systems. Another extreme situation may be the physical destruction, or reduced functionality of an extremely critical piece of infrastructure such as the GSM home location register [a database with details of each cellular phone subscriber authorized to use the GSM network].
Radio Interference	Interference is unlikely to be caused by a destructive event, but it is worth considering loss of service in any form as a potential life threatening situation. For example, during the 2006 Australian Tennis Open in Melbourne, Australia, IBM was conducting a radio frequency identification (RFID) demonstration. However, this demonstration interfered with Vodaphone’s GSM network affecting customers of that network in the vicinity of the demonstration. There was a potential tragedy in this case if someone required the ability to contact emergency services.

Unmaintainable Infrastructure	The consequence of an event may cause the loss of a critical dependency (such as fuel or gas) or render it unmaintainable due to lack of physical access due to an event. A quantity of communication equipment survived the initial impact of Hurricane Katrina in New Orleans, but as generators ran out of fuel and with no physical access to transport additional fuel, service was eventually lost.
Network Isolation and Upstream Faults	The core of most networks is shared amongst a number of different types of traffic. Furthermore, as network operators use IP transit in the core for voice traffic, routing problems can affect the network in different ways. This can affect wireless voice over Internet protocol (WVoIP) services more commonly as these are typically deployed over consumer grade broadband connections. For example, last year a hardware failure at a Sydney data center affected VoIP customers in at least three states and two service providers.
Lack of Capacity (or Network Meltdown)	Occurs when the sheer volume of traffic far exceeds the available capacity. The problem is further compounded as, in GSM for example, considerably less capacity exists for establishing a call than exists for delivery. So while a cell may have spare capacity for carrying established calls, the system may become overwhelmed with the volume of users trying to establish new calls.

As a result of these issues, the chief technical challenge when responding to an HA/DR event is the rapid deployment of communication systems, regardless if the affected area previously had an existing communications infrastructure or—as in the case with most large disasters—the preexisting communications network has been severely degraded or destroyed. Therefore, responding organizations must be prepared to bring their own ICT capabilities into the HA/DR operating environment in order to achieve a common architecture as depicted in Figure 10 (Manoj & Baker, 2007).

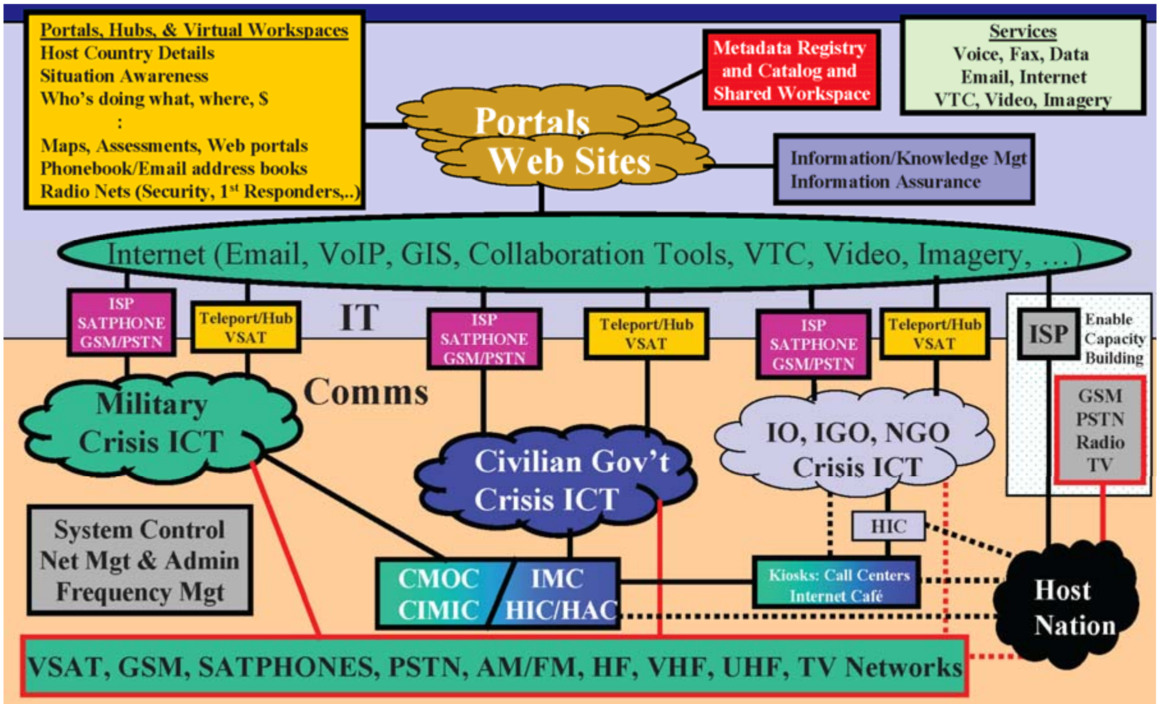


Figure 10. Common ICT Response Architecture for HA/DR (From Christman, Kramer, Starr, & Wentz, 2006)

According to UNESCAP (2010), "building such capacity of major communication means at a fully operational level may be beyond the capability of most developing countries" (p. 8). Therefore, a rapidly deployable ICT capacity to support responding entities such as DoD should include proven, reliable commercial off-the-shelf systems to establish, restore, and expand communications following major disasters. Organizations and governments should also be prepared to respond with arrangements for rapid shipment, installation, operation, and service provisions for the ICT systems to be utilized (UNESCAP, 2010).

C. ICT EMPLOYMENT AND UTILIZATION IN HA/DR

1. Background

The rapid, continuous evolution in commercial ICT has contributed many invaluable tools and removed numerous barriers to technical interoperability, resulting in the technical means to facilitate collaborative information environments (CIEs) for coordination (Christman, Kramer, Starr, & Wentz, 2006). There are countless ICT systems that could be used by responding entities for HA/DR through both commercial and military offerings; however, instead of defaulting to the cheapest or newest technologies available, it is first important to identify the appropriate communications capabilities required to meet the unique challenges faced in an HA/DR environment. As Denning (2006) pointed out, the quality of HA/DR response from an ICT perspective does not depend on “response planning or on new equipment, but on the quality of the network that came together to provide relief” (p. 15). Table 3 outlines the specific functional needs and challenges faced during the disaster response phase.

Table 3. Communication Capacity Needs During the Response Phase (After UNESCAP, 2010)

Within the first three hours of disaster occurrence, for major disaster affected areas	
Functional Needs	**Major Issues and Challenges**
Reporting to disaster management authorities	Availability of ground-based satellite and mobile
Communication among local and higher government authorities	
Monitoring and warning of secondary disasters	Availability of ground and satellite-based connections; Local cellular mobile service and satellite mobile
Within the first 24 hours of disaster occurrence, for major disaster affected areas	
Functional Needs	**Major Issues and Challenges**
Communication between field teams, relevant government authorities, and supporting organizations	Availability of ground and satellite-based connections; Local cellular mobile service; Satellite mobile; Wi-Fi; Rapid deployable satellite communications (SatCom) terminals; Congestion of cellular and satellite mobile

Beyond the 24 hours threshold, for major disaster affected areas	
Functional Needs	**Major Issues and Challenges**
Field news gathering and reporting	Availability of ground and satellite-based connection; Local cellular mobile service; Satellite mobile; Rapid deployable SatCom terminals; Wi-Fi; Congestion of cellular and satellite mobile systems
Communication among field teams and local coordinators, and among field team members	Availability of ground and satellite-based connections; Enough satellite mobile phones; Emergency communication vehicles; Wi-Fi; Network congestion of cellular and satellite mobile; High cost of satellite mobile calls; Interoperability and frequency interference among CB radios
Communication among government authorities, international organizations and international field teams	Availability of ground-based connection; Local cellular mobile service; Satellite mobile; Wi-Fi; SatCom terminals; Congestion of cellular and satellite mobile;
Communication of victims with their family connections	Availability of ground and satellite-based connections; Local cellular mobile service; Satellite mobile; Congestion of cellular and satellite mobile

Creating a CIE during HA/DR for multiple agencies, governments, NGOs, and industry is possible with commercial off-the-shelf technologies available today. These ICT systems are critical to a unified, successful response effort. Figure 11 illustrates the vast types of media that can be used to create a CIE, and is based on the assumptions by Christman et al. (2006) that:

> (1) The Internet, satellite links and cellular phones will be the preferred media for communicating and sharing information among the civil-military participants; (2) Commercial satellite service will likely be a primary means of gaining access from remote areas and to the Internet; (3) A common suite of ICT capabilities [e.g., a "toolbox" containing cell phones, radios, satellite phones, very small aperture terminal (VSAT) satellite systems, personal digital assistants (PDAs), laptops, workstations, Wi-Fi networks, collaboration tools, global positioning system (GPS) receivers, geographic information system (GIS) products] can be selectively packaged and tailored to meet the anticipated ICT operational support needs. (pp. 13–14)

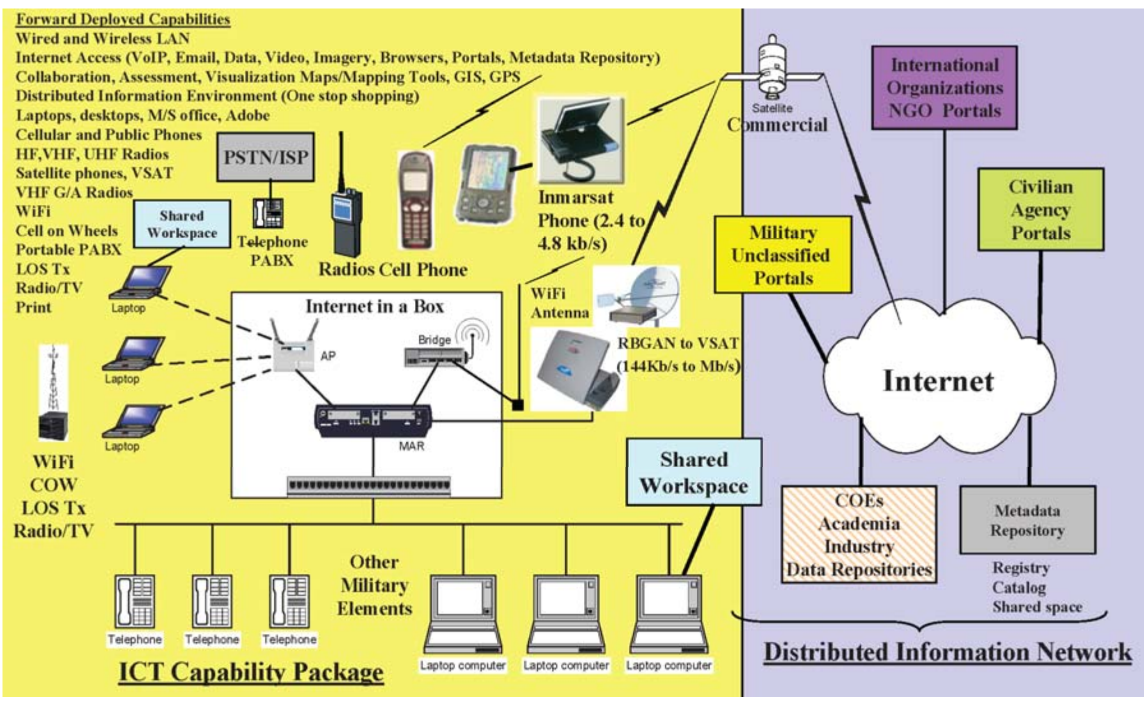


Figure 11. Commercial ICT Capabilities and Collaboration/Information Sharing Arrangements (From Christman, Kramer, Starr, & Wentz, 2006)

The 2010 UNESCAP report concurred with Christman et al. regarding the primary types of ICT used in disaster response when it concluded:

> To ensure the communication services during major disasters that may interrupt ground-based connectivity, satellite-based connectivity and services should be arranged to form the core of the standby, redundant and rapid deployable capacity for early disaster management stages. Satellite-based connectivity could be used either for cellular mobile and IP systems, or for direct mobile and Internet access. Satellite-based mobile, Internet and short message services (SMS) are the most reliable, accessible and rapid deliverable communication means for disaster management communications. They may also overcome the "last-mile" difficulty met by many developing countries and small island nations. (p. 9)

2. Hastily Formed Networks

ICT scientific developments and the growth of commercial products have resulted in the creation of a variety of flexible, scalable, and rapidly deployable civil-military ICT packages using off-the-shelf terrestrial wireless and commercial satellite systems and services (Wentz, 2006). These products and services come together in the HA/DR environment to create hastily formed networks (HFNs), which consist of rapidly deployable, ad hoc, IP-based networks generated using a variety of ICT systems. HFNs are an effective implementation of ICT as they facilitate a rapid, efficient humanitarian response by providing crisis communications where normal communications infrastructure is degraded or destroyed (Nelson, Steckler, & Stamberger, 2011). As shown in Figure 12, HFNs consist of three main material layers—physical, network, and application—with an overarching layer representing the human and social aspects of HA/DR.

Human/ Cognitive	Social/ Cultural	Organizational	Political	Economic
Application	Text • Email • Chat • SMS	Voice • Push-to-Talk • Cellular • VoIP • Sat Phone • Landline	Video / Imagery • VTC • GIS • Layered Maps	Specialized • Collaboration • Situational Awareness • Command/ Control • Integration
Network	Wired • DSL • Cable • Satellite (fixed)	Wireless Local • Wi-Fi • PAN • MAN	Wireless Long Haul • WiMax • Microwave • HF over IP	Satellite Broadband • VSAT • BGAN
Physical	Power • Fossil Fuel • Renewable	Human Needs • Shelter • Water • Fuel • Food	Physical Security • Force Protection • Access/ Authorization	Operations Center • Network Security • Command/ Control • Leadership

Figure 12. HFN Architecture Model (After Nelson, Steckler, & Stamberger, 2011)

From an ICT perspective and for the purposes of this research, the primary focus is the network layer, specifically the wireless and satellite network portions, since the wired infrastructure is likely to be damaged or destroyed. Typically, these networks consist of three levels: (1) wireless local area networks (WLANs), (2) wireless point-to-point/backhaul connections, and (3) satellite-based Internet connectivity. The three main technologies for these levels in disaster response are Wi-Fi/802.11 (including meshed wireless), WiMAX/802.16, and BGAN/VSAT, respectively, as depicted in Figure 13 (Nelson, Steckler, & Stamberger, 2011).

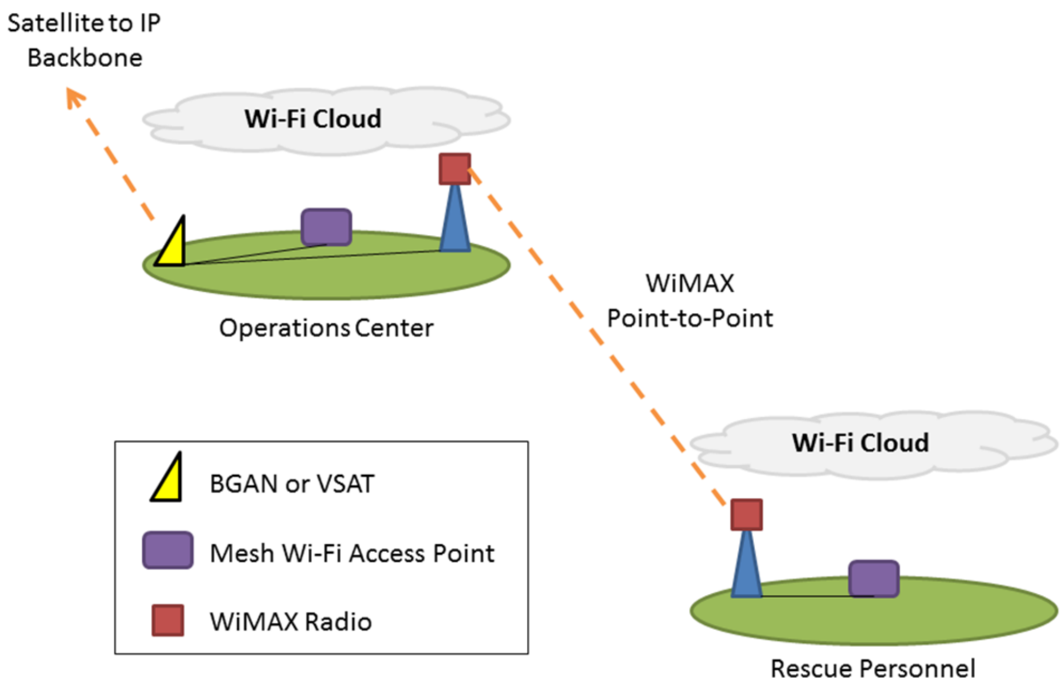


Figure 13. Example of a Three Level HFN Solution

3. Wireless Networks

Response coordination at disaster sites can be greatly enhanced by both data and voice communications that are possible due to the wide availability of wireless networking technologies for wireless point-to-point/backhaul communications, WLANs, and wireless mesh networks. The vast majority of wireless data networks utilized in the HA/DR environment are based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 and 802.16 standards.

a. IEEE 802.11/Wi-Fi

IEEE 802.11 is a group of standards for WLANs that were first released in the late 1990s. IEEE 802.11 is more popularly known as wireless fidelity, or Wi-Fi, a trademark and brand name term of the Wi-Fi Alliance for products using the IEEE 802.11 family of standards shown in Table 4.

Table 4. Comparison of 802.11 Wireless Protocols

Protocol	Release Date	Frequency	Max Data Rate
a	1999	5 GHz	54 Mbps
b	1999	2.4 GHz	11 Mbps
g	2003	2.4 GHz	54 Mbps
n	2009	2.4 / 5 GHz	300 Mbps

The 802.11 logical architecture contains several main components: station (STA), wireless access point (AP), independent basic service set (IBSS), basic service set (BSS), distribution system (DS), and extended service set (ESS). Some 802.11 logical architecture components, such as STAs and wireless APs, correspond directly to hardware devices. The wireless STAs contain an adapter card or an embedded device to provide wireless connectivity, while the wireless AP functions as a bridge between the wireless STAs and the existing network backbone. The wireless networks can be grouped into three sets of components—IBSS, BSS, and ESS—as shown in Figure 14.

- IBSS (or ad-hoc WLAN): wireless network used where no access to a DS is available consisting of at least two STAs;
- BSS (or infrastructure WLAN): wireless network consisting of a single wireless AP supporting one or multiple wireless clients. All STAs in a BSS communicate through the AP, which provides connectivity to the network backbone and bridging functionality between one STA and another STA or a node on the DS;
- ESS: set of interconnected BSSs connected to the same wired network that appears as a single BSS to any associated STA. APs of multiple BSSs are interconnected by the DS, allowing for STA mobility since they can move from one BSS to another (Microsoft, 2003).

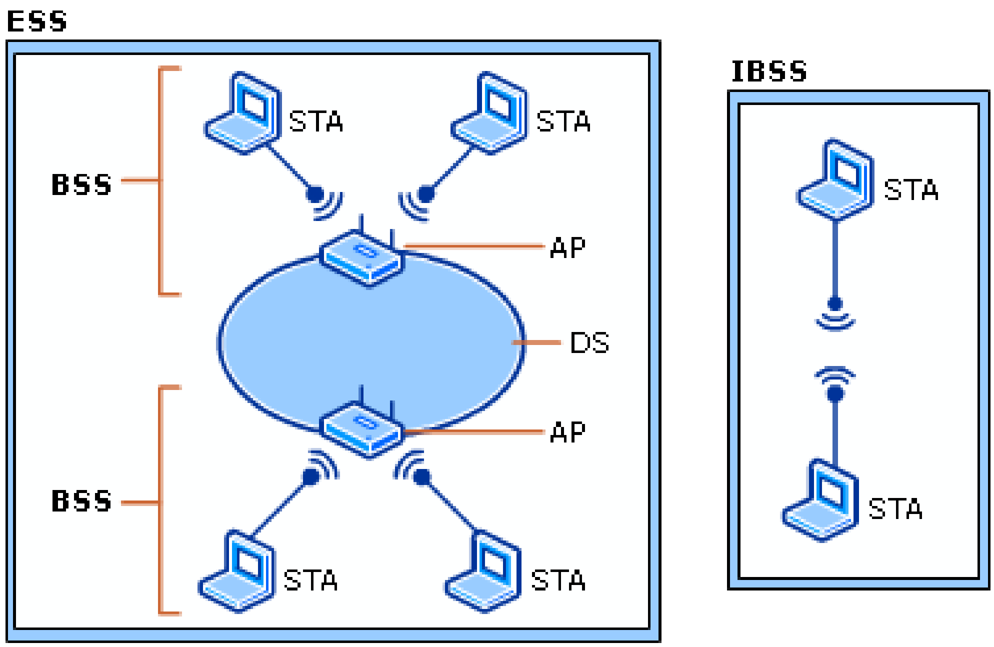


Figure 14. Wi-Fi (802.11) Architecture (From Microsoft, 2003)

Without a physical connection between nodes, wireless links are vulnerable to eavesdropping and information theft. Therefore, the IEEE 802.11 standard has defined two types of authentication methods—open system and shared key.

- Open System: a wireless device can join any network and receive any messages that are not encrypted;
- Shared Key: only those devices that possess the correct authentication key can join the network, as shown in Figure 15. Examples of security mechanisms for shared key authentication include Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA), and WPA2 (Netgear, 2005).

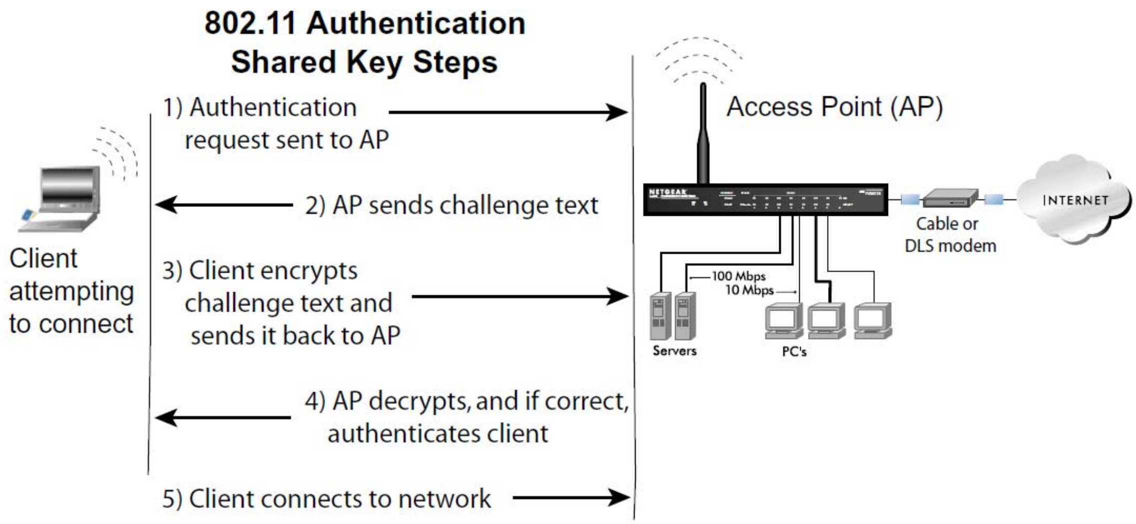


Figure 15. Wi-Fi (802.11) Security Authentication (From Netgear, 2005)

b. Wireless Mesh Networks

Another emerging trend with 802.11 is the development of technologies to "mesh" together the wireless nodes of a network without the need for a wired management backbone, forming a wireless mesh network (WMN). Network devices in the WMN can self-organize into temporary, ad hoc networks that arise and disperse in response to user needs. As shown in Figure 16, WMNs are comprised of two types of nodes: mesh routers and wireless clients. These nodes automatically establish an ad hoc network and maintain the mesh connectivity by dynamically self-organizing and self-configuring. To accomplish this, mesh routers contain additional routing functions and are usually equipped with multiple wireless interfaces of one or more wireless access technologies to support mesh networking. When combined with the typical routing functions in a conventional wireless router, a mesh router can achieve the same coverage with much lower transmission power through multi-hop communications. Despite the differences, mesh and conventional wireless routers are usually based on a similar hardware platform (Akyildiz & Wang, 2005).

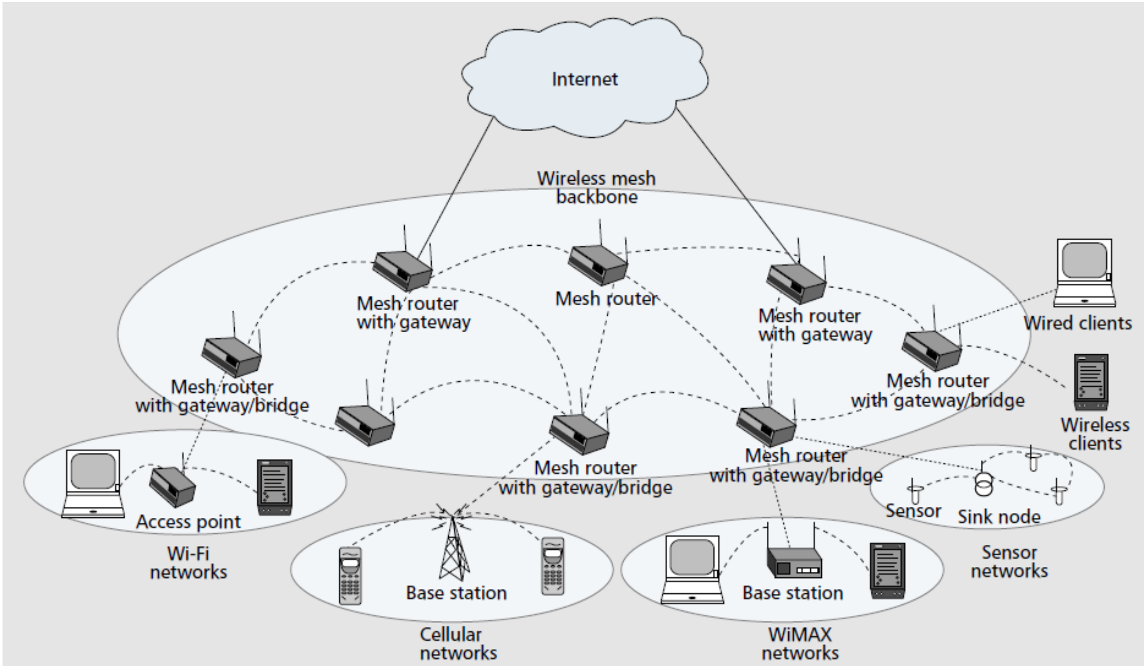


Figure 16. Example of Wireless Mesh Network Infrastructure
(From Akyildiz & Wang, 2005)

Since WMNs are fully distributed, multi-hop wireless networks, they can be highly effective for emergency response due to easy deployment and reconfiguration capability (Manoj, Tamma, Blair, & Rao, 2011). Currently, the IEEE is developing the finalized 802.11s standard for WMNs. Some industry manufacturers are already embracing 802.11s in its draft form, although most others continue to utilize proprietary technologies.

c. IEEE 802.16/WiMAX

IEEE 802.16 is a group of wireless broadband standards for wireless metropolitan area networks (WMANs) that were was first released in the early 2000s. 802.16 is more popularly known as Worldwide Interoperability for Microwave Access, or WiMAX, a trademark and brand name term of the WiMAX Forum used to promote compatibility and interoperability of products using the IEEE 802.16 family of standards.

IEEE 802.16 is a wireless digital communications technology providing wireless transmission of data, voice, and video over long distances, delivering point-to-point or point-to-multipoint connectivity in mobile and fixed configurations as depicted in Figure 17. WiMAX uses orthogonal frequency division multiplexing to achieve spectral efficiency resulting in high data rates and overall system capacity. Although there is no uniform global licensed spectrum for 802.16, the standards have specified both licensed and non-licensed operations in the 2–10 GHz and 10–66 GHz ranges. The WiMAX Forum currently supports continued rapid standardization and user adoption efforts for the 2.3 GHz, 2.5 GHz, and 3.5 GHz frequency bands, but is also working with operators and equipment manufacturers to expand the frequency allocation to cover identified key spectrum bands such as the 700 MHz bands previously used for analog television (WiMAX Forum, 2012).

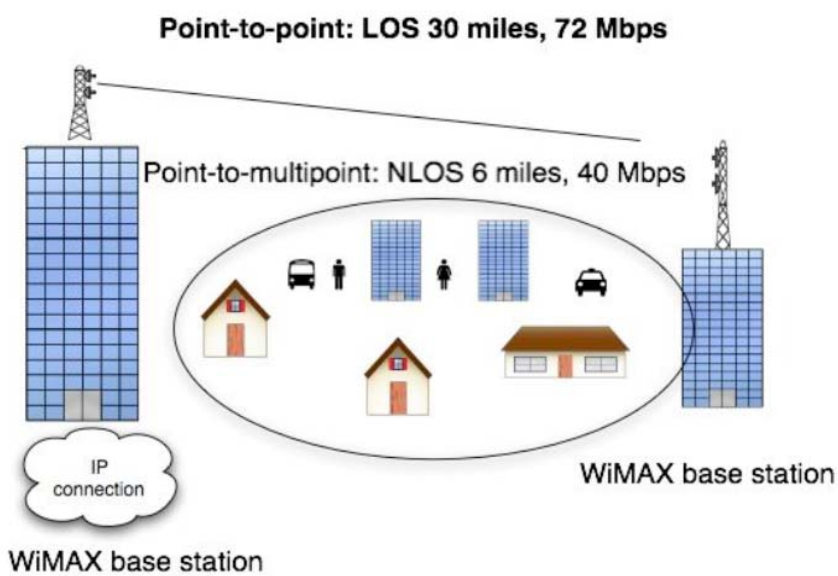


Figure 17. Example of Fixed WiMAX Applications (From Ohrtman, 2006)

Most current deployments of 802.16 typically reach 40 megabits per second (Mbps) up to 30 miles in a fixed, line-of-sight (LOS) configuration. Additionally, the emergence of the updated 802.16m standard in 2011 promises up to 1 gigabit per second (Gbps) for fixed configurations and 100Mbps mobile, non-line of sight (NLOS)

configurations in the near future. Additionally, it offers competitive advantages such as mobility, large area coverage (i.e., the last mile), quality of service, and cost effectiveness over the other wireless technologies with similar capabilities (Sithirasenan & Almahdouri, 2010).

4. Broadband Global Area Network

Mobile satellite systems (MSS) are a proven solution used to provide communication services to mobile users in an HA/DR environment due to unique capabilities in terms of robustness, wide area coverage, and broadcast/multicast capabilities (Chini, Giambene, & Kota, 2010). Christman et al. (2006) proposed that, "commercial satellites today can provide reasonable cost connectivity to virtually any place on Earth. As a result, they have become a key enabler for extending ICT services to remote, devastated or disadvantaged areas" for HA/DR operations (p. 8). Broadband Global Area Network (BGAN)—a satellite-based voice and data service from Inmarsat—is one industry-leading example for this type of technology.

Inmarsat was the operator of the first global mobile satellite communications system for mariners to maintain communications across the oceans and to call for help in an emergency. The Inmarsat-4 (I-4) series of satellites, as depicted in Figure 18, were developed by an international team of space technologists from Europe, the U.S., and Canada, with the European satellite manufacturer EADS Astrium as the lead contractor to build the three I-4 satellites at a cost of about $1.5B (Inmarsat, 2010).

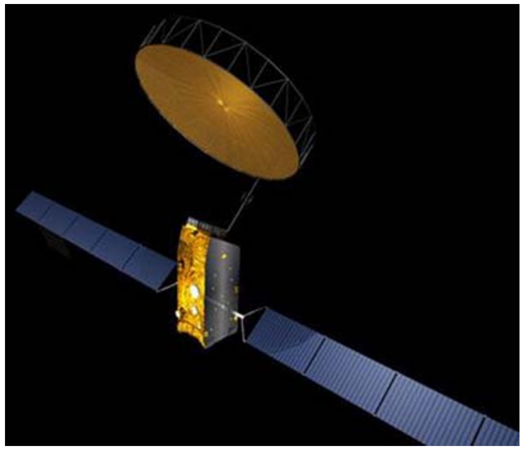


Figure 18. Inmarsat-4 Satellite (From European Space Agency, 2006)

The I-4s, upon initial launch in 2005, set a new benchmark for mobile satellite communications in terms of their power, capacity and flexibility, and are expected to continue in commercial operation until 2020 and possibly beyond. All Inmarsat satellites, including the three I-4s, fly in geosynchronous orbit at 35,786km above the Earth. This allows the BGAN constellation to cover the entire planet simultaneously, with the exception of the extreme Polar Regions, as shown in Figure 19 (Inmarsat, 2010).

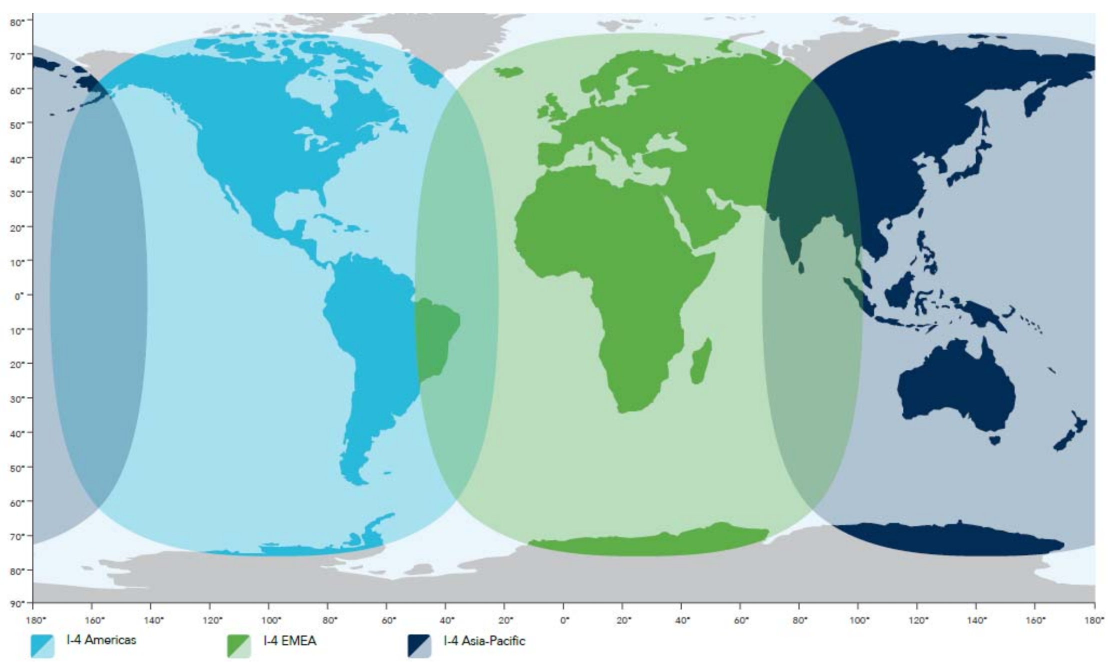


Figure 19. Global BGAN Coverage (From Inmarsat, 2009)

I-4 satellites are unique in their ability to generate hundreds of high-power spot beams. Each I-4 can generate 19 wide beams and more than 200 narrow spot beams for land-mobile communications, allowing communications up to 492 kilobits per second (kbps) to three classes of portable user terminals that vary in capability from Class 1 (most capable) to Class 3 (least capable), as shown in Table 5.

Table 5. Classes of BGAN Terminals (After Joint Systems Integration Command, 2006)

Type	Description
Class 1	▪ Professional applications ▪ Extremely dusty, rainy, cold, or hot conditions ▪ 492 kbps downstream / upstream
Class 2	▪ Multi-user terminal for professional and semi-professional uses ▪ Light and focused on user-friendliness ▪ More interconnection features that Class 3 and can be shared by several users ▪ 464 kbps downstream / 448 kbps upstream
Class 3	▪ Single-user terminal ▪ Focused on cost efficiency for light users ▪ Fewer features and accessorial than Classes 1 / 2 ▪ Not weatherproof ▪ 384 kbps downstream / 240 kbps upstream

Additionally, BGAN supports both circuit-switched and packet-switched voice and data services as detailed in Table 6 through the utilization of space-based and terrestrial infrastructure described in Figure 20 (Chini, Giambene, & Kota, 2010).

Table 6. BGAN Communications Capabilities (From Inmarsat, BGAN Overview, 2009)

Capability	Description
Standard Internet Protocol (IP)	For e-mail, Internet and intranet access via a secure virtual private network (VPN) connection at speeds up to 492 kbps over a shared channel.
Streaming IP	Guaranteed data on demand at rates in excess of 384 kbps. Data-rate can be chosen on a case-by-case basis, depending on application. Also supports Integrated Services Digital Network (ISDN) at 64 kbps.
Phone/Fax	Make fax or phone calls at the same time as accessing your data applications. Voice-mail and other standard 3rd generation (3G) mobile supplementary services are also available.
Text	Send and receive text messages via your laptop—up to 160 characters—to or from any mobile phone.

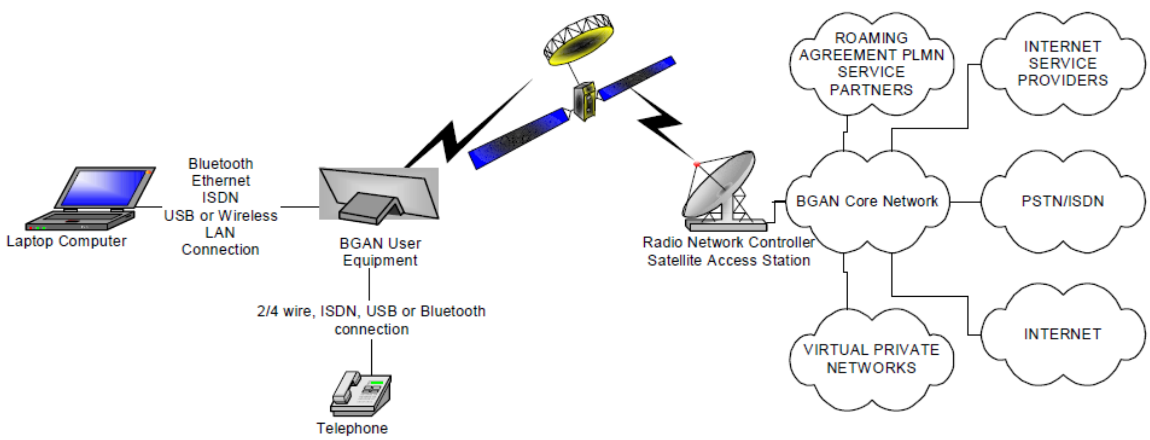


Figure 20. BGAN Overview (From Skinnemoen, Johansen, & Eriksen, 2003)

Inmarsat's key customer base and applications for BGAN service goes beyond HA/DR, and includes defense, oil and gas, media, utilities, mining, and transportation. As a result, the key benefits of the technology as listed in Figure 21 are well tested and documented.

Key benefits

Reliable

- Continue operations unimpeded by disruption to terrestrial networks
- Bandwidth availability is maintained as other agencies enter a disaster area, with network capacity dynamically reallocated to areas of high demand
- Range of highly robust satellite terminals that can withstand challenging environments and extreme temperatures
- 24/7 customer support through our worldwide network of partners

Highly compact

- Can be easily carried between locations in a backpack or hand luggage enabling immediate voice and broadband data connectivity
- Vehicular interior units take up minimal space in the car, with a discreet tracking antenna mounted on the roof

Simultaneous voice and broadband data

- Quickly establish field communications in the absence of terrestrial infrastructure
- Send and receive data more efficiently, including status reports, photos and video footage, and carry out standard administrative tasks
- Rescue workers can speak to off-site teams while sending a live video update
- Send live video broadcasts from the field, enabling media companies to promote awareness of the situation

Easy to use and manage

- Quick and easy to set up and shut down when you need to move to a new location
- Minimal technical expertise required – can be deployed by more field workers
- One solution for all your voice and data communications

Competitively and flexibly priced

- Significantly lower costs for both terminals and airtime compared with previous mobile satellite services and no set-up costs
- Can be deployed by multiple field teams, enabling real-time communications from more locations
- Flexible pricing packages, including post-pay and prepay, to help manage your costs

Flexible

- There are terminals that enable an instant wireless LAN so that remote teams can share a single BGAN connection
- With a vehicular BGAN terminal you can access high-speed data while on the move
- BGAN supports both ISDN and IP connectivity solutions so integrates seamlessly with your regional office network infrastructure
- Compatible with a wide range of standard networking and connectivity solutions: wireless routers, VPNs, thin-client software, FTP applications
- Can be used without a laptop interface

Figure 21. Key Benefits of BGAN for Humanitarian Aid (From Inmarsat, BGAN Applications: Aid, 2009)

D. SUMMARY

The U.S. government has continued its commitment to a robust humanitarian response effort as the world faces increasing quantity and severity of natural disasters. Subsequently, ICT system utilization in the HA/DR environment has become increasingly relevant and critical to successful response. Although numerous commercial systems and services such as Wi-Fi, WiMAX, and satellite-based IP connectivity are currently available to meet the needs of DoD, government agencies, NGOs, and foreign entities, essential ICT design characteristics will be identified in Chapter III to facilitate selection of the best technologies for the HA/DR environment.

THIS PAGE INTENTIONALLY LEFT BLANK

III. CHARACTERISTICS AND EVALUATION METHODOLOGY

A. ESSENTIAL ICT CHARACTERISTICS FOR HA/DR RESPONSE

Christman et al. (2006) indicated there is a broad consensus that ICT is a necessary enabler for effective HA/DR operations. Further, organizations such as the UNESCAP have recommended that policymakers should consider encouraging investment in wireless voice and data networks as they can offer opportunities to achieve rapid, cost-effective connectivity for areas susceptible to disaster (2009, p. 4). As a result, a growing number of participants in these operations—government organizations, military forces, NGOs, host nations, and industry—are utilizing ICT capabilities when deploying to HA/DR environments; however, recent disaster responses indicate "there is no default or standardized suite of equipment, databases, or operational protocols" utilized when these organizations deploy and attempt to work together for humanitarian purposes (p. 19).

Post-disaster environments present unique challenges typically not encountered through the traditional use of commercial ICT systems. In order to meet these challenges, certain features must be considered when developing, acquiring, and deploying technologies for disaster response. The following five essential ICT characteristics are vital to ensure the successful deployment of communications-enabling technologies in an HA/DR environment:

- Portability
- Environmental Durability
- Internal Power
- Standards-Based Connectivity
- Ease of Configuration

1. Portability

The ability to deploy ICT systems worldwide, particularly to remote locations, is a key characteristic for the HA/DR mission. The UNESCAP (2010) specified rapid deployment and high mobility as characteristics that should be addressed in developing [an] emergency communications capability" (p. 14). Rapid deployment is important in order to "make trans-boundary movement smoothly in a short time," particularly concerning transportation methods (UNESCAP, 2010, p. 14). Additionally, high mobility ensures speedy deployment and installation to "some geographically difficult areas," where the ICT systems "should be robust enough for easy handling and safe shipment, including when necessary for air-drop and man-power carrying" (UNESCAP, 2010, p. 14).

2. Environmental Durability

The relatively unpredictable scenarios surrounding the times, places, and environments of HA/DR missions—particularly natural disasters—necessitates that ICT systems are capable of operating in harsh conditions. According to Midkiff and Bostian (2002), "all equipment used for emergency and disaster response must be rugged to survive transport and harsh conditions and easy to use by responders who need technology to be 'transparent' so that they may focus on life-critical tasks" (p. 3). Specifically, the UNESCAP (2010) identified that deployment uncertainty must be given consideration when developing an emergency ICT capability, and that "emergency communication tools are preferably handy, durable to all weathers and mobile even to mountainous terrains as the exact location of disaster occurance is difficult to predict" (p. 14).

3. Internal Power

When deploying to a disaster environment, it should be assumed that electrical power will initially be limited or completely unavailable in remote deployment locations due to the damage caused to any pre-existing commercial infrastructure. Therefore, responding agencies should consider deploying with stand-alone power systems—both externally independent and within systems (Christman et al., 2006). Deployable, high-

output alternate power systems such as solar, wind, and hydrogen fuel cell technologies are vital to HA/DR, but are beyond the scope of this thesis. However, it is important to consider individual ICT systems that include changeable, on-board battery systems for use in remote locations and to bridge-the-gap during periods without external power sources.

Vehicles are a logical source of power, but are typically parked in a staging area at a safe distance from disaster affected area. In most cases, running electrical cords back to vehicles or generators from ICT deployment locations is not a practical option. This creates the requirement for portable, self-contained, battery-powered devices that can be deployed at a disaster site to provide communications coverage (Arisoylu, Mishra, Rao, & Lenert, 2005).

4. Standards-Based Connectivity

When assessing ICT characteristics for HA/DR missions, it is vital to consider the interoperability of deployable technologies in potential disaster response locations. The UNESCAP (2010) indicated that attention must be given to "comercially available services to the region that have demonstrated or expressed their affordability and contuinity," and are "compatible with existing services…of the countries" (p. 16).

ICT usability based on technological standards adoption is a critical factor for terrestrial wireless and saelllite-based systems. According to a 2008 Federal Communications Commission (FCC) report to Congress in response to the 9/11 terrorist attacks, FCC Chairman Kevin Martin concluded that, "a contributing factor affecting vulnerability and overall reliability of emergency responder communication systems is the lack of interoperability…open, standard interfaces would help to mitigate the information systems interoperability problem" (pp. 22–23). Deploying new communications systems in areas where partial infrastructures remain following an HA/DR event can create numerous challenges such as interference from existing networks and the dependency of the population on prior systems. Therefore, it is best practice to utilize ICTs that can address both scenarios through the use of accepted technological standards (Manoj & Baker, 2007). Support of common standards such as the Transmission Control Protocol/Internet Protocol (TCP/IP) Internet protocols and

IEEE 802.11 and 802.16 wireless standards is important because it allows rapid integration of commercial off-the-shelf technologies (COTS) into responder ICT architecture (Arisoylu, Mishra, Rao, & Lenert, 2005).

5. Ease of Configuration

The final essential characteristic of ICT systems in an HA/DR environment is ease of configuration. The typical responder to a disaster event is most likely skilled in areas such as medical care or emergency management, and does not have in-depth information technology expertise. Ideally, ICT systems could utilize a "zero configuration" approach by pre-staging all necessary system settings prior to deployment so end users could avoid network management in the field (Midkiff & Bostian, 2002). Unfortunately, the HA/DR environment can change rapidly, so responders must remain flexible in order to adjust capabilities to match evolving needs (Nelson, Steckler, & Stamberger, 2011). Therefore, it is important that deployed ICT systems are reasonably simple to deploy and configure in the field. Frassl et al. (2010), identified usability as a key non-functional requirement when describing the characteristics for systems used in disaster management missions, where they concluded:

> The user works in a stressful situation, under high pressure and in an exhausting environment and is not a computer expert. The user should not be occupied by setting up and operating software, preventing him/her from mission-related tasks. In consequence the goal is to offer a simple and easy to use system while reducing any configuration effort as much as possible. Only essential functionality should be offered in order to minimize complexity. If configuration or setup is unavoidable, the system needs to support the user to do this. (p. 3)

By ensuring rapidly deployable ICT systems are free of highly technical configurations requiring specialized knowledge, software, or equipment, responding personnel can minimize their time spent on managing HFNs and focus on their primary HA/DR responsibilities.

B. EVALUATION METHODOLOGY

In order to select the best possible capabilities for successful operations in an HA/DR environment, it is necessary to create a quantifiable metric based on the key

desirable ICT design characteristics. For each characteristic, a system undergoing evaluation will be assigned a descriptive reference (insufficient, limited, and exceptional) and a corresponding value (zero, one, and two, respectively) based upon how well the system meets the stated requirements for each characteristic shown in Tables 8–12. Following evaluation, the value assigned to each characteristic will be summed for an overall score, where:

$$\sum \text{(Characteristic Values)} = \text{Overall Score}$$

The overall score can range in values from zero (system characteristics are completely insufficient for HA/DR use) to eight (system characteristics are exceptional for HA/DR deployment). Table 7 provides an example of the matrix for an evaluated system. In this hypothetical case, the system was exceptional in the area of environmental durability (value of two), limited in the areas of portability, standards-based connectivity, and ease of configuration (total value of three), and insufficient in the area of internal power (value of zero). Overall, this system achieved a score of five out of a possible ten.

Table 7. Example ICT System Evaluation Matrix

Evaluation Matrix: Example System			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability		●	
Environmental Durability			●
Internal Power	●		
Standards-Based Connectivity		●	
Ease of Configuration		●	
	1 (value = 0)	**3 (value = 3)**	**1 (value = 2)**
	System Total: 5 / 10		

In order to adequately and effectively assign a descriptive reference and corresponding value for the five characteristics, each must be clearly defined in either quantifiable or true/false terms for each value to be assigned.

1. Portability

Nelson, Steckler, and Stamberger identified portability as a key constraint for ICT deployment in HA/DR environment. Specifically, they contended that equipment should be slim and lightweight since “disaster responders must often physically carry equipment into hard-to-access areas, requiring equipment to be portable” (Nelson, Steckler, & Stamberger, 2011, p. 468). Therefore, ICT systems should be able to fit into a container that can be carried-on (vice checked) with an international airline, while remaining light enough for reasonable man-portability. Although there is no international standard for carry-on sizes or weights, the maximum size carry-on bag for most airlines is 45 linear inches—or sum of the height, width, and depth (Federal Aviation Administration, 2009). In order to capture sizes and weights of ICT equipment appropriate for disaster response missions, industry-standard protective cases from Pelican Products, Inc. were used as a guide. Pelican Cases are characterized by a watertight, crushproof, and dust proof design, an open cell core with solid wall design, O-ring seals, automatic pressure equalization valves, and stainless steel hardware for rust protection. The cases used as a guide are also rated to keep contents dry, even if submerged in one meter deep water for 30 minutes (Pelican Products, 2012).

To achieve an exceptional rating, the evaluated system must fit inside the largest case categorized as “small” by Pelican—the 1400 Case. The 1400, shown in Figure 22, has maximum internal dimensions of 0.31 cubic feet as listed in Table 8.

Figure 22. Pelican 1400 Case (From Pelican Products, 2012)

Table 8. Pelican 1400 Case Specifications (From Pelican Products, 2012)

Physical & Environmental	
Exterior Size (L x W x D)	13.37” x 11.62” x 6.00” (33.9 x 29.5 x 15.2 cm)
Interior Size (L x W x D)	11.81” x 8.87” x 5.18” (30 x 22.5 x 13.2 cm)
Weight	4.41 lbs (2 kg)
Interior Volume	0.31 cubic feet (8.89 cubic decimeter)
Buoyancy Max	20.06 lbs (9.1 kg)
Temperature Range	- 40° / 210° F (- 40° / 99° C)

To achieve a limited rating, the evaluated system must fit inside the largest non-rolling case that is under the 45 linear inch allowable carry-on size for most airlines and categorized as “medium” by Pelican—the 1520 Case. The 1520, shown in Figure 23, has maximum internal dimensions of 0.91 cubic feet as listed in Table 9.

Figure 23. Pelican 1520 Case (From Pelican Products, 2012)

Table 9. Pelican 1520 Case Specifications (From Pelican Products, 2012)

Physical & Environmental	
Exterior Size (L x W x D)	19.78” x 15.77” x 7.41” (50.2 x 40 x 18.8 cm)
Interior Size (L x W x D)	18.06” x 12.89” x 6.72” (45.9 x 32.7 x 17.1 cm)
Weight	9.35 lbs (4.24 kg)
Interior Volume	0.91 cubic feet (25.64 cubic decimeter)
Buoyancy Max	63 lbs (28.58 kg)
Temperature Range	- 40º / 210º F (- 40º / 99º C)

The interior dimensions of the Pelican cases rounded down to the nearest whole inch will be the constraints for the portability characteristic. In addition, to ensure ease of man-portability at the disaster site, systems evaluated with exceptional portability must weight under 7.5 pounds, and systems evaluated with limited portability must weight under 15 pounds. Combinations of size and weight constraints are shown in Table 10.

Table 10. Evaluation Criteria for Portability

Portability		
Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Too large and/or heavy for international commercial air carry-on baggage. Weight: 15 lbs or greater {or} Size: > 18" x 12" x 6" (L x W x D)	Small/light enough for international commercial air carry-on baggage, but too large/heavy for easy man-portability in an extreme HA/DR environment. Weight: < 15 lbs {and} Max Size: 18" x 12" x 6" (L x W x D)	Small/light enough for international commercial air carry-on baggage and easy man-portability in an extreme HA/DR environment. Weight: < 7.5 lbs {and} Max Size: 11" x 8" x 5" (L x W x D)
Example: Item weights over 15 lbs or will not fit in an airline carry-on case.	Example: Item weights under 15 lbs and will fit in a Pelican 1520 Case.	Example: Item weights under 7.5 lbs and will fit in a Pelican 1400 Case.

2. Environmental Durability

The primary measure of environmental durability is the International Electrotechnical Commission (IEC) international standard defined in IEC 60529, which outlines degrees of protection provided by enclosures of electronics. Specifically, IEC 60529 provides a numerical code to express the protection of the equipment inside an enclosure against the ingress of solid foreign objects and harmful effects due to the ingress of water. The Ingress Protection, sometimes referred to as International Protection, code (IP code) indicates the level of protection by designating the letters "IP" followed by two numerals representing solid foreign object access (first numeral) and water ingress protection (second numeral). For example, a product with the IP code of IP 68 would be dust-tight (no ingress of dust) and capable of continuous immersion in water. Tables 11 and 12 indicate the degrees of protection outlined in IEC 60529 (National Electrical Manufacturers Association [NEMA], 2002).

Table 11. IEC Degrees of Protection Against Solid Foreign Objects (After NEMA, 2002)

First Numeral	Level of Protection
0	Not protected
1	Protected against solid foreign objects ≥ 50 mm diameter
2	Protected against solid foreign objects ≥ 12.5 mm diameter
3	Protected against solid foreign objects ≥ 2.5 mm diameter
4	Protected against solid foreign objects ≥ 1 mm diameter
5	Dust-protected (dust shall not penetrate in quantity to interfere with satisfactory operation of the apparatus)
6	Dust-tight (no ingress of dust)

Table 12. IEC Degrees of Protection Against Water Ingress (From NEMA, 2002)

Second Numeral	Level of Protection
0	Not protected
1	Protected against vertically falling water drops
2	Protected against vertically falling water drops when enclosure tilted up to 15 degrees
3	Protected against spraying water
4	Protected against splashing water
5	Protected against water jets
6	Protected against powerful water jets
7	Protected against the effects of temporary immersion in water
8	Protected against the effects of continuous immersion in water

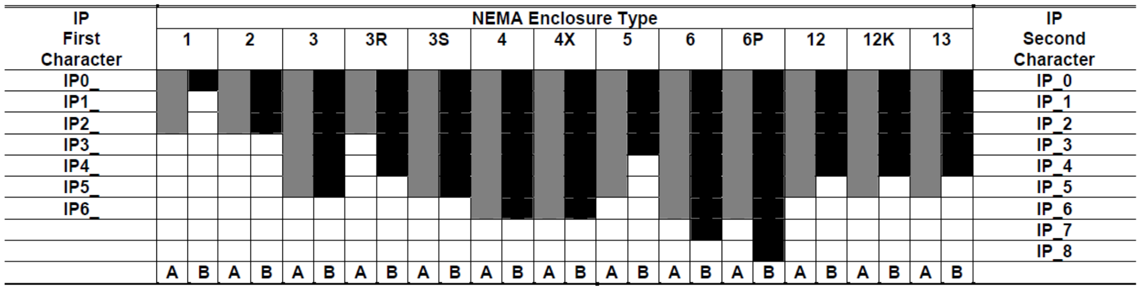
In 2004, the American National Standards Institute (ANSI) adopted IEC 60529 as an American National Standard. Since IEC 60529 has been recognized as the de facto U.S. and international standard for electronic environmental durability, it will be utilized as the principle metric for this characteristic (NEMA, 2004). An ICT system must be rated as IP 67 (dust-tight and protected against effects of temporary immersion in water) or better to be considered exceptional, while a rating of IP 54 (dust protected and protected against splashing water) or better will warrant a limited rating as defined in Table 13.

Table 13. Evaluation Criteria for Environmental Durability

Environmental Durability		
Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
System is not well suited for an outdoor environment. Rating does not meet IP 54	System meets accepted standards for limited environmental durability. Rating meets or exceeds IP 54	System meets accepted standards for harsh environmental durability. Rating meets or exceeds IP 67
<u>Example</u>: System intended for home/business use. Limited outside durability.	<u>Example</u>: System is dust-protected and protected against water jets.	<u>Example</u>: System is dust-tight and protected against effects of temporary immersion in water.

In addition, the National Electrical Manufacturers Association (NEMA) has published a brief comparison with its NEMA 250 enclosure type ratings. NEMA 250—although not as widely utilized as IP Codes for ICT equipment—provides specific requirements for additional protections such as construction, icing, and gasket oil resistance that are not covered in IEC 60529. Although IP codes cannot be converted to NEMA type ratings due to these additional requirements, Figure 24 provides a summary of the NEMA ratings that exceed the specification requirements for the respective IEC IP code designations.

CONVERSION OF NEMA ENCLOSURE TYPE RATINGS TO IEC 60529 ENCLOSURE CLASSIFICATION DESIGNATIONS (IP)
(CANNOT BE USED TO CONVERT IEC CLASSIFICATION DESIGNATIONS TO NEMA TYPE RATINGS)



A = A shaded block in the "A" column indicates that the NEMA Enclosure Type exceeds the requirements for the respective IEC 60529 IP First Character Designation. The IP First Character Designation is the protection against access to hazardous parts and solid foreign objects.

B = A shaded block in the "B" column indicates that the NEMA Enclosure Type exceeds the requirements for the respective IEC 60529 IP Second Character Designation. The IP Second Character Designation is the protection against the ingress of water.

Figure 24. Comparison of IEC IP Codes and NEMA Type Ratings (From NEMA, 2002)

For example, a NEMA Type 3 rating exceeds the requirements for IP 55 and a NEMA Type 6 rating exceeds the requirement for IP 67. Therefore, corresponding NEMA ratings can also be used to identify criteria for environmental durability (NEMA, 2002).

3. Internal Power

Although most ICT systems lack this capability, internal power—even when only viable for limited durations—is necessary in the HA/DR environment. Frassl et al. concluded that power autonomy is significant because "disaster missions are unpredictable with respect to the availability of any local infrastructure…electric power may not be available…the system has to bridge that gap with internal power sources" (Frassl, Lichtenstern, Khider, & Angermann, 2010, p. 4). With this rationale, the presence of an internal battery to fully operate a system is a defining factor for this characteristic as shown in Table 15. ICT systems with an internal power source are rated as limited, but the battery must also be easily removable in the field to be rated as exceptional. For the purposes of this research, battery run time will not be included due to the differences in system power requirements, battery materials and capacity, and constantly changing variables such as data transfer rates and temperature.

Table 14. Evaluation Criteria for Internal Power

Internal Power		
Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Does not include any internal battery power source(s).	Includes an internal battery source, but it is intended to be removable/ interchangeable.	Includes an internal, removable/interchangeable battery source.
Example: Device with no internal power source.	Example: Internal battery not designed for field removal, requiring special tools and/or extensive labor for removal/replacement.	Example: Removing internal battery requires simple or no tools for rapid removal/replacement.

4. Standards-Based Connectivity

Interoperability is a critical component for wireless-based connections such as Wi-Fi and WiMAX in the disaster response area. By employing widely accepted standards from international organizations, it is possible to integrate ICT components and end users across the HFN. It must be noted that many systems utilize multiple wired and wireless connections consisting of both standard and non-standard technologies within a single piece of hardware. Therefore, for the purposes of evaluating the standards-based connectivity characteristic, only the primary data interface used to configure the device and the primary data interface used for access by end users will be considered. Systems that primarily utilize an internationally-accepted technological standard for both configuration and end users are evaluated as exceptional, interfaces based on draft specifications of a potential internationally-accepted technological standard are considered limited, and draft, proprietary, or country-specific technologies (i.e., military specifications) are considered insufficient.

Table 15. Evaluation Criteria for Standards-Based Connectivity

Standards-Based Connectivity		
Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Technology is a draft standard, proprietary, or limited to a particular country/organization.	An internationally recognized standard is only present for either configuration or end users (not both).	Technology is an internationally recognized standard for both configuration and end users.
Example: All device communications require special, non-standard interfaces (i.e., DoD only).	Example: End users can use a technology such as Wi-Fi (802.11a/b/g/n), but configuration requires a special, non-standard connection.	Example: Standard technology such as Wi-Fi (802.11a/b/g/n) that is widely used.

5. Ease of Configuration

When evaluating key areas that should be addressed when developing an emergency communications capability, the UNESCAP identified simplicity of installation and operation, noting that "equipment installation should be easy and service arrangements made well before the happening of disasters" (2010, p. 15). Further, the rapid deployment of ICT requires not only swift placement of the technologies in the HA/DR environment, but also rapid network set-up achievable by simplicity of configuration in order to establish critical communications (Midkiff & Bostian, 2002). As a result, ICT systems requiring installation of special software or additional specialized equipment for configuration are rated as limited, while systems that can be configured through a built-in interface without additional software or equipment are rated as exceptional.

Table 16. Evaluation Criteria for Ease of Configuration

Ease of Configuration		
Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
System only configurable by a certified technician/ engineer or requires manufacturer for configuration changes.	System requires installation of special software for configuration. {or} System requires additional specialized equipment for configuration.	System can be configured through a built-in interface requiring no additional software or equipment.
Example: Typical users deployed in the field cannot reconfigure device.	Example: Configuration requires certain licensed software or equipment such as a spectrum analyzer.	Example: System configurable through a web browser and standard data connection.

C. SUMMARY

The essential ICT characteristics of portability, environmental durability, internal power, standards-based connectivity, and ease of configuration have been identified as vital to the successful deployment of communications-enabling technologies in an HA/DR environment. Additionally, specific parameters for each essential characteristic have been proposed to support the evaluation and comparison of ICT systems. In order to demonstrate the function and applicability of the ICT evaluation methodology, commercial technologies typically used to form an HFN for disaster response will be evaluated and discussed in Chapter IV.

.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. EXAMPLES OF ICT EVALUATION

The following technologies were selected to demonstrate the ICT evaluation methodology due to availability of the equipment in the HFN Center at the Naval Postgraduate School (NPS) and applicability to the HA/DR environment. These systems have been used in both real-world disasters such as Hurricane Katrina in 2005 and the 2010 earthquake in Haiti, as well as HA/DR-related exercises, conferences, and technology demonstrations such as U.S. Pacific Command (PACOM)-sponsored Pacific Endeavor 2011 conference held in Singapore, the 2011 California International Airshow in Salinas, California, as well as a project developing Independently Powered, Command, Control, and Communications (IPC3) with the California Homeland Security Consortium (CHSC) from NPS. Finally, it must be noted that the intent of this research is not to endorse or recommend any particular commercial product or service, but rather to use real-world technologies to best illustrate examples for system evaluation and comparison. All three levels of a likely HFN architecture—(1) wireless local area networks (WLANs), (2) wireless point-to-point/backhaul connections, and (3) satellite-based Internet connectivity, as shown in Figure 25—will be considered for evaluating and comparing ICT systems.

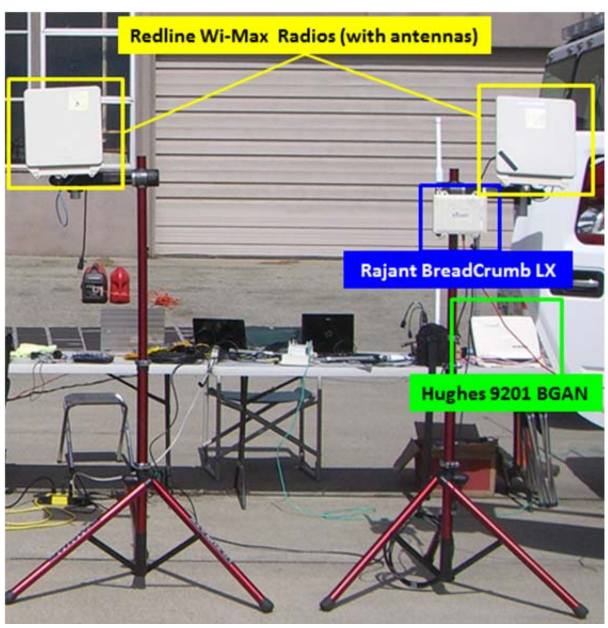


Figure 25. Staging ICT Systems at the 2011 California International Airshow

A. WIRELESS LOCAL AREA NETWORKS

1. Rajant BreadCrumb LX4

a. Description

The Rajant BreadCrumb LX4—shown in Figure 26—is a rugged, portable, multi-radio, wireless transceiver that forms a wireless mesh network when used in conjunction with other BreadCrumb devices, and contains between two and four radios supporting open-standard IEEE 802.11a/b/g protocols for data, voice, and video applications (Rajant Corporation, 2011). Full system specifications are outlined in Table 17.

Figure 26. Rajant BreadCrumb LX4 (From Rajant Corporation, 2011)

Table 17. Rajant BreadCrumb LX4 Technical Specifications (After Rajant Corporation, 2011)

Technical Specifications: Rajant BreadCrumb LX4	
Physical	
Size (L x W x D)	7.68” x 7.35” x 2.40” (195 x 187 x 61 mm)
Weight (with Battery)	4.74 lbs (2.15 kg)
Environmental	
IP/NEMA Rating	IP 67
Operating Temperature	-40–176 F (-40–80 C)
Power	
External Power	24–48 V DC
Internal Battery	No
Data Interface	
Primary User	Wi-Fi (IEEE 802.11a/b/g)
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	USB
System Capability	
Frequencies	900MHz, 2.4 GHz, 4.9GHz, 5.0 GHz
Data Rate	Max: 54 Mbps
Range	Max: 1 mile (1.6 km) Environment, Output Power, and Antenna Dependent
Configuration Interface	Required Rajant BC | Commander Software
External Configuration Requirements	N/A

b. *Evaluation*

The Rajant BreadCrumb LX4 was assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 18.

Table 18. Analysis of Characteristics for Rajant BreadCrumb LX4

Characteristic Analysis: Rajant BreadCrumb LX4	
	Description of Characteristics
Portability	• Weight under 7.5 lbs • Size under 11” x 8” x 5” • Determination: *Exceptional*
Environmental Durability	• Meets IP 67 criteria • Determination: *Exceptional*
Internal Power	• No internal power supply • Determination: *Insufficient*
Standards-Based Connectivity	• Primary user interface is Wi-Fi • Primary configuration interface is Ethernet • Determination: *Exceptional*
Ease of Configuration	• Requires special licensed software • Determination: *Limited*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 19.

Table 19. System Evaluation Matrix for Rajant BreadCrumb LX4

Evaluation Matrix: Rajant BreadCrumb LX4			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability			●
Environmental Durability			●
Internal Power	●		
Standards-Based Connectivity			●
Ease of Configuration		●	
	1 (value = 0)	**1 (value = 1)**	**3 (value = 6)**
	System Total: 7 / 10		

2. Persistent Systems Wave Relay Quad Radio Router

a. Description

The Persistent Systems Wave Relay Quad Radio Router—shown in Figure 27—is a scalable high performance wireless solution for deploying large wireless mesh networks or mobile ad-hoc networking (MANET) systems, containing up to four separate wireless radios to simultaneously provide multi-channel, multi-hop backhaul and connectivity to other nodes. This configuration offers a single solution for wireless mesh networking requirements through deployment flexibility, dynamic self-configuring routing, throughput optimized route selection, robust fault tolerance, and scalability (Persistent Systems, 2011). Full system specifications are outlined in Table 20.

Figure 27. Persistent Systems Wave Relay Quad Radio Router (From Persistent Systems, 2011)

Table 20. Persistent Systems Wave Relay Quad Radio Router Specifications (After Persistent Systems, 2011)

Technical Specifications: Persistent Systems Wave Relay Quad Radio Router	
Physical	
Size (L x W x D)	8.5” x 6.0” x 2.0” (216 x 152 x 51 mm)
Weight (with Battery)	3.2 lbs (1.45 kg)
Environmental	
IP/NEMA Rating	IP 67
Operating Temperature	-40–185 F (-40–85 C)
Power	
External Power	8–48 V DC Device Input: IEEE 802.3af Power Over Ethernet (POE) or power port
Internal Battery	No
Data Interface	
Primary User	Wi-Fi (IEEE 802.11a/b/g)
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	NATO Standard U-283/U Voice Connector
System Capability	
Frequencies	700 MHz, 900 MHz, 2.3–2.5 GHz, 3.5 GHz, 4.9 GHz, 5.0 GHz
Data Rate	Max: 37 Mbps (UDP) / 27 Mbps (TCP)
Range	Max: 2 miles (3.2 km) Environment, Output Power, and Antenna Dependent
Configuration Interface	Built-In Web Server
External Configuration Requirements	N/A

b. *Evaluation*

The Persistent Systems Wave Relay Quad Radio Router assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 21.

Table 21. Analysis of Characteristics for Persistent Systems Wave Relay Quad Radio Router

Characteristic Analysis: Persistent Systems Wave Relay Quad Radio Router	
	Description of Characteristics
Portability	• Weight under 7.5 lbs • Size under 11" x 8" x 5" • <u>Determination</u>: *Exceptional*
Environmental Durability	• Meets IP 67 criteria • <u>Determination</u>: *Exceptional*
Internal Power	• No internal power supply • <u>Determination</u>: *Insufficient*
Standards-Based Connectivity	• Primary user interface is Wi-Fi • Primary configuration interface is Ethernet • <u>Determination</u>: *Exceptional*
Ease of Configuration	• Built-in web application • No additional equipment required • <u>Determination</u>: *Exceptional*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 22.

Table 22. System Evaluation Matrix for Persistent Systems Wave Relay Quad Radio Router

Evaluation Matrix: Persistent Systems Wave Relay Quad Radio Router			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability			●
Environmental Durability			●
Internal Power	●		
Standards-Based Connectivity			●
Ease of Configuration			●
	1 (value = 0)	**0 (value = 0)**	**4 (value = 8)**
	System Total: 8 / 10		

B. WIRELESS POINT-TO-POINT/BACKHAUL CONNECTIONS

1. Redline Communications AN-80i

a. Description

The Redline Communications AN-80i—shown in Figure 28—can be software configured to create point-to-point (PTP) communication links between network locations and high speed point-to-multipoint (PMP) access links between users or their organizational networks. The AN-80i's enhanced IEEE 802.16 radio delivers high capacity, high throughput, long range and low latency, making it ideal for specialized applications in the petroleum industry, military organizations, and governments (Redline Communications, 2012). The An-80i is sold as a radio only, but will be assessed with a

standard Redline Communications flat-panel antenna (model A2209MTFW) for realistic evaluation. Antenna size and weight were added to the AN-80i full system specifications outlined in Table 23.

Figure 28. Redline Communications AN-80i Deployed for the NPS ICP3 Project

Table 23. Redline AN-80i (with Antenna) Technical Specifications (After Redline Communications, 2012)

Technical Specifications: Redline AN-80i (with antenna)	
Physical (Radio and Antenna)	
Size (L x W x D)	12” x 12” x 2.6” (305 x 305 x 66.5 mm)
Weight	7.1 lbs (3.2 kg)

Environmental	
IP/NEMA Rating	IP 67
Operating Temperature	-40–140 F (-40–60 C)
Power	
External Power	Device Input: POE (IEEE 802.3af)
Internal Battery	No
Data Interface	
Primary User	Ethernet (IEEE 802.3) / RJ-45
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	N/A
System Capability	
Frequencies	3.3–3.8 GHz, 3.65–3.7 GHz, 4.94–4.99 GHz, 5.25–5.35 GHz, 5.47–5.725 GHz, 5.725–5.85 GHz
Channel Sizes	3.5, 5, 7, 10, 14, 20, 28, 40 MHz
Data Rate	Max: 90 Mbps
Range	Max: 50 miles (80km) Environment, Output Power, and Antenna Dependent
Configuration Interface	Built-In Web Server (Optional: Redline Management Software)
External Configuration Requirements	N/A

b. *Evaluation*

The Redline Communications AN-80i was assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 24.

Table 24. Analysis of Characteristics for Redline Communications AN-80i

Characteristic Analysis: Redline AN-80i	
	Description of Characteristics
Portability	• Weight under 7.5 lbs • Size exceeds 11” x 8” x 5,” but under 18” x 12” x 6” • Determination: *Limited*
Environmental Durability	• Meets IP 67 criteria • Determination: *Exceptional*
Internal Power	• No internal power supply • Determination: *Insufficient*
Standards-Based Connectivity	• Primary user interface is Ethernet • Primary configuration interface is Ethernet • Determination: *Exceptional*
Ease of Configuration	• Built-in web application • No additional equipment required • Determination: *Exceptional*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 25.

Table 25. System Evaluation Matrix for Redline Communications AN-80i

Evaluation Matrix: Redline AN-80i			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability		●	
Environmental Durability			●
Internal Power	●		
Standards-Based Connectivity			●
Ease of Configuration			●
	1 (value = 0)	**1 (value = 1)**	**3 (value = 6)**
	System Total: 7 / 10		

2. Airaya WirelessGRID-300

a. Description

The Airaya WirelessGRID-300—shown in Figure 29—utilizes integrated outdoor architecture of outdoor bridges to provide simple installation and maximum range and capacity in a weatherproof design. Employing a multiple input, multiple output (MIMO) OFDM radio design and adaptive modulation in the 5GHz frequency range, WirelessGRID-300 outdoor backhaul radios operate at a range of up to 30 miles and at speeds up to 300 Mbps (Airaya, 2012). Unlike the Redline Communications AN-80i, the WirelessGRID-300 includes an integrated flat-panel antenna for evaluation. Full system specifications are outlined in Table 26.

Figure 29. Airaya WirelessGRID-300 (After Airaya, 2012)

Table 26. Airaya WirelessGRID-300 Technical Specifications (After Airaya, 2012)

Technical Specifications: Airaya WirelessGRID-300	
Physical (Radio and Antenna)	
Size (L x W x D)	15” x 15” x 4” (380 x 380 x 120 mm)
Weight	~12 lbs (5.4 kg)
Environmental	
IP/NEMA Rating	IP 66 / NEMA Type 4
Operating Temperature	-22–140 F (-30–60 C)
Power	
External Power	Device Input: POE (IEEE 802.3af)
Internal Battery	No
Data Interface	
Primary User	Ethernet (IEEE 802.3) / RJ-45
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	N/A
System Capability	
Frequencies	4.9–4.99 GHz, 4.94–4.99 GHz, 4.8–6.1 GHz, 5.25–5.35 GHz, 5.47–5.725 GHz, 5.725–5.85 GHz
Channel Sizes	15, 20, 40, 50 MHz
Data Rate	Max: 300 Mbps
Range	Max: 30 miles (50km) Environment, Output Power, and Antenna Dependent
Configuration Interface	Built-In Web Server
External Configuration Requirements	N/A

b. Evaluation

The Airaya WirelessGRID-300 was assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 27.

Table 27. Analysis of Characteristics for Airaya WirelessGRID-300

Characteristic Analysis: Airaya WirelessGRID-300	
	Description of Characteristics
Portability	• Weight under 15 lbs • Size exceeds 18” x 12” x 6” Determination: *Insufficient*
Environmental Durability	• Does not meet IP 67 requirements, but exceeds IP 54 criteria Determination: *Limited*
Internal Power	• No internal power supply Determination: *Insufficient*
Standards-Based Connectivity	• Primary user interface is Ethernet • Primary configuration interface is Ethernet Determination: *Exceptional*
Ease of Configuration	• Built-in web application • No additional equipment required Determination: *Exceptional*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 28.

Table 28. System Evaluation Matrix for Airaya WirelessGRID-300

Evaluation Matrix: Airaya WirelessGRID-300			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability	●		
Environmental Durability		●	
Internal Power	●		
Standards-Based Connectivity			●
Ease of Configuration			●
	2 (value = 0)	**1 (value = 1)**	**2 (value = 4)**
	System Total: 5 / 10		

C. SATELLITE-BASED INTERNET CONNECTIVITY

1. Hughes 9201

a. Description

The Hughes 9201—shown in Figure 30—is a fully IP-compatible terminal certified for operation on Inmarsat's BGAN global communications service with simultaneous IP packet and circuit-switched data communications via standard universal serial bus (USB), Ethernet, integrated services digital network (ISDN), and 802.11 WLAN interfaces (Hughes Network Systems, 2010). Full system specifications are outlined in Table 29.

Figure 30. Hughes 9201 BGAN Inmarsat Terminal (From Hughes Network Systems, LLC)

Table 29. Hughes 9201 Technical Specifications (After Hughes Network Systems, 2010)

Technical Specifications: Hughes 9201	
Physical	
Size (L x W x D)	13.6” x 10.8” x 2.0” (345 x 275 x 50 mm)
Weight	6.2 lbs (2.8 kg)
Environmental	
IP/NEMA Rating	IP 55
Operating Temperature	13–140 F (-25–60 C)
Power	
External Power	110–240 V AC (20 V DC) / Device Input: 11.1 V DC
Internal Battery	Yes
Battery Specifications	Lithium Ion, Removable, Rechargeable, 36 hr Stand-By
Data Interface	
Primary User	Wi-Fi (802.11b)
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	USB, ISDN
System Capability	
IP Data	Send/Receive: up to 492 kbps
Voice	4 kbps, 3.1 kHz voice
SMS	160 Characters
Configuration Interface	Built-In Web Server (Optional: Inmarsat BGAN LaunchPad Software)
External Configuration Requirements	N/A

b. Evaluation

The Hughes 9201 was assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 30.

Table 30. Analysis of Characteristics for Hughes 9201

Characteristic Analysis: Hughes 9201	
	Description of Characteristics
Portability	• Weight under 7.5 lbs • Size exceeds 11” x 8” x 5,” but under 18” x 12” x 6” • Determination: *Limited*
Environmental Durability	• Does not meet IP 67 requirements, but exceeds IP 54 criteria • Determination: *Limited*
Internal Power	• Internal removable/rechargeable battery • Determination: *Exceptional*
Standards-Based Connectivity	• Primary user interface is Wi-Fi • Primary configuration interface is Ethernet • Determination: *Exceptional*
Ease of Configuration	• Built-in web application • No additional equipment required • Determination: *Exceptional*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 31.

Table 31. System Evaluation Matrix for Hughes 9201

Evaluation Matrix: Hughes 9201			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability		●	
Environmental Durability		●	
Internal Power			●
Standards-Based Connectivity			●
Ease of Configuration			●
	0 (value = 0)	**2 (value = 2)**	**3 (value = 6)**
	System Total: 8 / 10		

2. Thrane & Thrane Explorer 500

a. Description

The Thrane & Thrane Explorer 500—shown in Figure 31—is the most used BGAN terminal in the world with performance providing simultaneous high quality voice and broadband access at speeds up to 464 kbps and LAN, USB, Bluetooth and phone/fax interfaces, as well as portability, weighing just over 3 lbs and smaller than a standard laptop (Thrane & Thrane, 2012). Full system specifications are outlined in Table 32.

Figure 31. Thrane & Thrane Explorer 500 (From Thrane & Thrane, 2012)

Table 32. Thrane & Thrane Explorer 500 Technical Specifications (After Thrane & Thrane, 2012)

Technical Specifications: Thrane & Thrane Explorer 500	
Physical	
Size (L x W x D)	8.6” x 8.5” x 2.1” (218 x 217 x 52 mm)
Weight (with Battery)	3.1 lbs (1.4 kg)
Environmental	
IP/NEMA Rating	IP 54
Operating Temperature	13–131 F (-25–55 C)
Power	
External Power	100–240 V AC (10–16 V DC) / Device Input: 15 V DC
Internal Battery	Yes
Battery Specifications	Lithium Ion, Removable, Rechargeable, 36 hr Stand-By
Data Interface	
Primary User	Ethernet (IEEE 802.3) / RJ-45
Primary Configuration	Ethernet (IEEE 802.3) / RJ-45
Other	USB, RJ-11 (phone/fax), Bluetooth 1.2
System Capability	
IP Data	Send: up to 448 kbps, Receive: up to 464 kbps
Voice	4 kbps, 3.1 kHz voice
SMS	160 Characters
Configuration Interface	Built-In Web Server (Optional: Inmarsat BGAN LaunchPad Software)
External Configuration Requirements	N/A

b. Evaluation

The Thrane & Thrane Explorer 500 was assessed based on the evaluation criteria for each essential characteristic, and resulted in the determinations described in Table 33.

Table 33. Analysis of Characteristics for Thrane & Thrane Explorer 500

Characteristic Analysis: Thrane & Thrane Explorer 500	
	Description of Characteristics
Portability	• Weight under 7.5 lbs • Size exceeds 11” x 8” x 5,” but under 18” x 12” x 6” • <u>Determination</u>: *Limited*
Environmental Durability	• Does not meet IP 67 requirements, but exceeds IP 54 criteria • <u>Determination</u>: *Limited*
Internal Power	• Internal removable/rechargeable battery • <u>Determination</u>: *Exceptional*
Standards-Based Connectivity	• Primary user interface is Ethernet • Primary configuration interface is Ethernet • <u>Determination</u>: *Exceptional*
Ease of Configuration	• Built-in web application • No additional equipment required • <u>Determination</u>: *Exceptional*

Based on the determinations for each characteristic, the quantitative results of the evaluation are summarized in Table 34.

Table 34. System Evaluation Matrix for Thrane & Thrane Explorer 500

Evaluation Matrix: Thrane & Thrane Explorer 500			
	Insufficient (value = 0)	*Limited (value = 1)*	*Exceptional (value = 2)*
Portability		●	
Environmental Durability		●	
Internal Power			●
Standards-Based Connectivity			●
Ease of Configuration			●
	0 (value = 0)	**2 (value = 2)**	**3 (value = 6)**
	System Total: 8 / 10		

D. SUMMARY

Six commercially-available ICT products from across all three levels of a prospective HFN architecture—(1) wireless local area networks (WLANs), (2) wireless point-to-point/backhaul connections, and (3) satellite-based Internet connectivity—were discussed and evaluated for comparison. Results of the evaluations will be compared and analyzed in Chapter V to determine the most effective solution for creating a HFN-based architecture from the assessed systems. Further, potential areas where the proposed evaluation methodology can be improved and expanded through future research will be discussed.

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSIONS AND FUTURE WORK

A. DISCUSSION OF FINDINGS

Based on the evaluations and comparisons of the systems in Chapter IV, the most effective assessed systems for creating a HFN-based architecture would include the Persistent Systems Wave Relay Quad Radio Router for WLAN, the Redline Communications AN-80i for wireless point-to-point/backhaul connections, and either the Hughes 9201 or the Thrane & Thrane Explorer 500 satellite-based Internet connectivity.

1. WLAN Evaluation and Comparison

Both of the WLAN devices scored well with the Rajant Breadcrumb LX4 scoring 7 /10 and the Persistent Systems Wave Relay Quad Radio Router scoring 8 / 10. Neither system had an internal battery power source, which was the main limiting factor for both devices. Additionally, the Wave Relay system achieved a higher score for the ease of configuration characteristic due to utilization of a built-in web application for configuration vice the specialized, licensed Rajant BC | Commander software required to configure the Breadcrumb LX4. When deploying to an HA/DR event, having the built-in configuration interface that can be accessed with a platform-independent web browser would provide a benefit over software such as BC | Commander that only operates on Windows or Linux, requires a special license key, and would necessitate workstations without the software to initiate a relatively large download in a bandwidth-constrained environment. Based on this evaluation and comparison, the Persistent Systems Wave Relay Quad Radio Router would be the preferred system.

2. Wireless Point-to-Point/Backhaul Connection Evaluation and Comparison

The wireless point-to-point devices both scored below the leading WLAN system with the Redline Communications AN-80i scoring 7 /10 and the Airaya WirelessGRID-300 scoring 5 / 10. Similar to the WLAN evaluations, the wireless point-to-point devices did not include any internal power supplies, instead only opting for POE injectors as the sole power source; however, the AN-80i excelled over the WirelessGRID-300 in

portability and environmental durability, scoring exceptional and limited, respectfully, for both characteristics. Based on this evaluation and comparison, the Redline Communications AN-80i would be the preferred system.

3. Satellite-Based Internet Connectivity Evaluation and Comparison

For BGAN satellite-based Internet devices, both the Hughes 9201 and the Thrane & Thrane Explorer 500 scored 8 / 10. Additionally, each device was evaluated equally for each characteristic—limited for portability and environmental durability, and exceptional for internal power, standards-based connectivity, and ease of configuration. For the purposes of this research, the evaluation and comparison concludes that either the Hughes 9201 or the Thrane & Thrane Explorer 500 would be an acceptable solution for HA/DR use; however, if an organization must make a decision between these two devices for use in the HA/DR environment, other characteristics and specifications would have to be evaluated and prioritized independently. For example, system advantages for both the 9201 and Explorer 500 could be placed together and compared as in Table 35 to determine the best fit for specific mission requirements of the organization.

Table 35. Satellite-Based Internet Connectivity System Comparison of Hughes 9201 and Thrane & Thrane Explorer 500

Satellite-Based Internet Connectivity System Comparison -- Advantages	
Hughes 9201	**Thrane & Thrane Explorer 500**
More Environmentally Durable	Lighter and Smaller
Internal Wi-Fi (802.11b) Access Point	Internal Bluetooth 1.2
Slightly Faster IP Data Capability	RJ-11 Jack for Standard Phone/Fax Line

B. FUTURE RESEARCH

The recent study by Bensahe and Cronin (2012) concluded that, "the demand for HA/DR missions is likely to increase in the coming years … the United States can and should work with its allies and partners to improve the global capacity to conduct these missions" (p. 23). Adopting the proposed evaluation and comparison methodology for selecting appropriate ICT for HA/DR will help responders face the increasing worldwide aid missions expected in the future. In addition, further research to develop essential characteristics and evaluation methodologies such as prioritization of characteristics, cost considerations, and exploring additional technologies can ensure utilization of the most effective and efficient ICT systems in the future.

1. Prioritization of Characteristics

The basis of the methodology in this research assumes that all essential characteristics are of equal importance; however, it may be necessary to prioritize the five characteristics based on particular missions or applications. For example, if an organization has a robust portable power generation system, then the internal power requirement may be of less importance than the other characteristics. Follow-on research may add weighted percentages to the quantified evaluations based on particular needs so the system "score" adequately addresses non-equivalent characteristic prioritization.

2. Cost as a Factor

A significant factor to consider when choosing a rapidly deployable ICT system for an organization is cost. The complexities with identifying and quantifying acceptable costs for different organizations and missions could be the basis for future research. Areas of consideration may include different cost thresholds for organizations (i.e., acceptable costs for a U.S. government agency may be prohibitive for an NGO) and specific consideration for the current global economic challenges.

3. Evaluation of Other ICT Systems

This research only evaluated systems that were available for operational familiarization and fit into the typical model for HFN deployment in a HA/DR

environment; however, numerous other technologies are also widely used in disaster response. Follow-on research can reevaluate the proposed essential characteristics and comparison methodology for a wider range of portable devices such as laptops, tablets, mobile phones, and GPS devices.

C. CONCLUSIONS

Reliance on ICT—particularly wireless data communications—is essential to a coordinated response among the large number and diverse types of disaster response organizations. Therefore, choosing the best and most effective ICT systems for use during HA/DR missions is vital to ensuring the overall success of response efforts. By utilizing the proposed quantifiable methodology based on essential system characteristics, decision makers can evaluate and compare rapidly deployable ICT systems to identify systems that are best suited for HA/DR, resulting in more effective cooperative utilization of these technologies to improve post-disaster responsiveness.

In recent decades, U.S. political leaders have opted to steadily increase the number of contingency operations when national interests were at stake or the nation was compelled by a moral responsibility to respond to humanitarian crises. Further, emerging countries such as Brazil, China, and India are investing in their international assistance capacities, making HA/DR one of the most promising areas to improve regional cooperation (Bensahe & Cronin, 2012). These reasons for conducting HA/DR operations are equally justified, and warrant continued work by industry, academia, government, and the responder community to ensure the ability to deploy the most effective technologies for communication and collaboration when disaster strikes in order to save lives and ease human suffering.

LIST OF REFERENCES

Airaya. (2012). 300 Mbps outdoor wireless backhaul: WirelessGRID-300 point-to-point wireless ethernet bridge. Retrieved February 9, 2012, from Airaya: http://www.airaya.com/products/WirelessGRID-300.asp

Akyildiz, I., & Wang, X. (2005). A survey on wireless mesh networks. I*EEE Communications Magazine, 43*(9), S23–S30.

Amin, S., & Goldstein, M. (Eds.). (2008). Data against natural disasters: establishing effective systems for relief, recovery, and reconstruction. Washington DC: World Bank.

Arisoylu, M., Mishra, R., Rao, R., & Lenert, L. A. (2005). 802.11 wireless infrastructure to enhance medical response to disasters. *AMIA Annual Symposium Proceedings, 2005* (pp. 1–5). Washington DC: American Medical Informatics Association.

Assistant Secretary of Defense for Networks & Information Integration/Department of DoD Chief Information Officer [ASD(NII)/DoD CIO]. (2009). Information and communications technology (ICT) capabilities for support of stabilization and reconstruction, disaster relief, and humanitarian and civic assistance operations (DoD Instruction 8220.02). Retrieved from www.dtic.mil/whs/directives/corres/pdf/822002p.pdf

Bensahe, N., & Cronin, P. M. (2012). *America's civilian operations abroad: understanding past and future requirements.* Washington DC: Center for a New American Security.

Chairman of the Joint Chiefs of Staff [CJCS]. (2009). *Joint Publication 3–29: foreign humanitarian assistance*. Washington DC: Department of Defense.

Chairman of the Joint Chiefs of Staff [CJCS]. (2010). *Joint Publication 1–02: Department of Defense dictionary of military and associated terms [as amended through 1/15/2012]*. Washington DC: Department of Defense.

Chini, P., Giambene, G., & Kota, S. (2010). A survey on mobile satellite systems. *International Journal of Satellite Communications and Networking, 28*(1), 29–57.

Christman, G., Kramer, F., Starr, S., & Wentz, L. (2006). Perspectives on information and communications technology (ICT) for civil-military coordination in crises. 2006 Command and Control Research and Technology Symposium: The State of the Art and the State of the Practice. San Diego.

Conway, J., Roughead, G., & Allan, T. (2007). A cooperative strategy for 21st century seapower. Washington DC: Department of Defense. Retrieved from www.navy.mil/maritime/Maritimestrategy.pdf

Conway, J., Roughead, G., & Allan, T. (2010). Naval operations concept 2010: implementing the maritime strategy. Washington DC. Retrieved from http://www.navy.mil/maritime/noc/NOC2010.pdf

Denning, P. J. (2006). Hastily formed networks. *Communications of the ACM, 49*(4), 15–20.

Dilley, M., Chen, R., Deichmann, U., Lerner-Lam, A., & Arnold, M. (2005). Natural disaster hotspots: a global risk analysis—synthesis report. Retrieved from Center For Hazards and Risk Research at Columbia University: http://sedac.ciesin.columbia.edu/hazards/hotspots/synthesisreport.pdf

European Space Agency. (2006). European Space Agency. Retrieved from Telecommunications and integrated applications: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=25844

Federal Aviation Administration. (2009). Carry-on baggage tips. Retrieved February 15, 2012, from Federal Aviation Administration: http://www.faa.gov/passengers/prepare_fly/baggage/

Franchi, A., & Sengupta, J. (2001). Technology Trends and Market Drivers for Broadband Mobile via Satellite: Inmarsat BGAN. European Space Agency, DSP 2001: *Seventh International Workshop on Digital Signal Processing Techniques for Space Communications. Inmarsat.* Retrieved from http://esamultimedia.esa.int/conferences/01C14/papers/6.1.doc

Frassl, M., Lichtenstern, M., Khider, M., & Angermann, M. (2010). Developing a system for information management in disaster relief. *Proceedings of the 7th International Information Systems for Crisis Response and Management [ISCRAM] Conference* (pp. 1–6). Seattle: ISCRAM.

Hughes Network Systems. (2010). Hughes 9201 BGAN Inmarsat terminal data sheet. Retrieved January 2012, from Hughes: http://www.hughes.com/HNS%20Library%20For%20Products%20%20Technology/9201-BGAN_HR.pdf

Inmarsat. (2009). BGAN applications: aid. Retrieved from Inmarsat: http://www.inmarsat.com/Downloads/English/BGAN/Collateral/BGAN_aid_solution_sheet_EN.pdf

Inmarsat. (2009). BGAN coverage. Retrieved from Inmarsat: http://www.inmarsat.com/Downloads/English/Land_services/Land_coverage.pdf

Inmarsat. (2009). BGAN overview. Retrieved from Inmarsat: http://www.inmarsat.com/Downloads/English/BGAN/Collateral/bgan_overview_brochure_EN.pdf

Inmarsat. (2010). The Inmarsat-4s. Retrieved from Inmarsat: http://www.inmarsat.com/About/Our_satellites/The_Inmarsat-4s.aspx?language=EN&textonly=False

Joint Systems Integration Command. (2006). Technical validation report: broadband global area network as an executive command and control enhancement. Retrieved from Inmarsat: http://www.inmarsat.com/Downloads/English/BGAN_as_an_EC2_Enhancement.pdf

Lindell, M., Prater, C., & Perry, R. (2007). *Introduction to emergency management*. Hoboken, NJ: Wiley.

Manoj, B. S., & Baker, A. H. (2007). Communication challenges in emergency response. *Communications of the ACM, 50*(3), 51–53.

Manoj, B. S., Tamma, B. R., Blair, P., & Rao, R. (2011). On non-invasive network measurement for emergency response wireless mesh networks. 2011 Fourth International Conference on the Applications of Digital Information and Web Technologies (ICADIWT) (pp. 183-–188). Stevens Point, WI: IEEE.

Martin, K. J. (2008). *FCC report to Congress: vulnerability assessment and feasibility of creating a back-up emergency communications system.* Washington DC: Federal Communications Commission [FCC].

Microsoft. (2003). Microsoft TechNet. Retrieved from How 802.11 wireless works: http://technet.microsoft.com/en-us/library/cc757419%28WS.10%29.aspx

Midkiff, S. F., & Bostian, C. W. (2002). *Rapidly-deployable broadband wireless networks for disaster and emergency response. The First IEEE Workshop on Disaster Recovery Networks (DIREN '02)*. New York. Retrieved from http://www.cwt.vt.edu/research/detail/disaster_response/Midkiff_Bostian_DIREN02.pdf

Mullen, M. (2011). *The national military strategy of the United States of America: redefining America's military leadership*. Washington DC: Department of Defense.

Munich RE. (2011). Natural catastrophes 1980 – 2010. Retrieved from Munich RE NatCat Service: http://www.munichre.com/app_pages/touch/naturalhazards/@res/pdf/NatCatSERVICE/focus_analyses/1980_2010_natural_catastrophes_percentage_distribution_per_continent_touch_en.pdf

Munich RE. (2011). Natural catastrophes 2010. Retrieved from Munich RE NatCat Service: http://www.munichre.com/app_pages/www/@res/pdf/natcatservice/annual_statistics/2010/2010_mrnatcatservice_natural_disasters2010_worldmap_touch_en.pdf

Munich RE. (2011). Natural catastrophes worldwide 1980–2010. Retrieved from Munich RE NatCat Service: http://www.munichre.com/app_pages/touch/naturalhazards/@res/pdf/NatCatSERVICE/focus_analyses/1980_2010_Paket_Welt_Fokus_Analysen_touch_en.pdf

Munich RE. (2011). Topics geo: natural catastrophes 2010. Retrieved from Munich RE: http://www.munichre.com/publications/302–06742_en.pdf

Munich RE. (2012). Munich RE Touch natural hazards. Retrieved January 28, 2012, from Munich RE: http://www.munichre.com/touch/naturalhazards/en/homepage/default.aspx

National Electrical Manufacturers Association [NEMA]. (2002). NEMA standards publication: a brief comparison of NEMA 250—enclosures for electrical equipment (1000 volts maximum) and IEC 60529—degrees of protection provided by enclosures (IP code). Rosslyn, VA: NEMA.

National Electrical Manufacturers Association [NEMA]. (2004). *ANSI/IEC 60529–2004: degrees of protection provided by enclosures (IP code) (identical national adoption)*. Rossln, VA: NEMA.

Nelson, C., Steckler, B. D., & Stamberger, J. A. (2011). The evolution of hastily formed networks for disaster response: technologies, case studies, and future trends. 2011 IEEE Global Humanitarian Technology Conference (pp. 467–475). Seattle: IEEE.

Netgear. (2005). Wireless networking basics. Retrieved from Netgear: http://documentation.netgear.com/reference/ita/wireless/pdfs/FullManual.pdf

Obama, B. (2010). *National security strategy.* Washington, DC: The White House.

Ohrtman, F. (2006). *WiMAX in 50 pages: A simple explanation to a complex subject.* Denver: Monnoz Publishing/WMX Systems.

Panetta, L. E. (2012). *Sustaining U.S. global leadership: priorities for 21st century defense.* Washington DC: Department of Defense. Retrieved from www.defense.gov/news/Defense_Strategic_Guidance.pdf

Pelican Products. (2012). Pelican Products 1400 Case. Retrieved February 12, 2012, from Pelican Products, Inc.: http://pelican.com/cases_detail.php?Case=1400

Pelican Products. (2012). Pelican Products 1520 Case. Retrieved February 12, 2012, from Pelican Products, Inc.: http://pelican.com/cases_detail.php?Case=1520

Persistent Systems. (2011). Quad Radio Router. Retrieved from Persistent Systems: Wave Relay: http://www.persistentsystems.com/pdf/PS_Quad.pdf

Rajant Corporation. (2011). BreadCrumb LX4 Portable Wireless Mesh Network Node. Retrieved from Rajant: http://www.rajant.com/pdf/Rajant_BreadCrumb_LX4_data_Sheet.pdf

Redline Communications. (2012). AN-80i Broadband Radio Platform datasheet. Retrieved from Redline Communications: http://www.rdlcom.com/en/resource-center/doc_download/1-an-80i-datasheet

Ring, J. W., Foo, E., & Looi, M. (2007). On ensuring contunity of mobile communications in a disaster environment. *Proceedings of the 2007 Research Network for a Secure Australia [RNSA] Security Technology Conference* (pp. 268–278). Melbourne: RNSA.

Sithirasenan, E., & Almahdouri, N. (2010). Using WiMAX for effective business continuity during and after disaster. *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference* (pp. 494–498). New York: ACM.

Skinnemoen, H., Johansen, T. V., & Eriksen, E. (2003). Ultra-portable multimedia satellite terminals for the BGAN satellite system. *2003 IEEE 58th Vehicular Technology Conference Proceedings* (pp. 2678–2682). Orlando: IEEE.

Thrane & Thrane. (2012). Explorer 500 technical specifications. Retrieved from Thrane & Thrane: http://www.thrane.com/Land%20Mobile/Products/~/media/Land%20Mobile%20New%20Content%20Aug09/Products/EXPLORER%20500/pdfs/EXPLORER_500_ProductSheet_LR%20pdf.ashx

UN Economic and Social Commission for Asia and the Pacific [UNESCAP]. (2009). *Policy brief on ICT applications in the knowledge economy*. New York: United Nations.

UN Economic and Social Commission for Asia and the Pacific [UNESCAP]. (2010). *Collaborative building of regional disaster communications capabilities*. New York: United Nations.

Wentz, L. (2006). An ICT primer: information and communication technologies for civil-military coordination in disaster relief and stabilization and reconstruction. Washington, DC: National Defense University Center for Technology and National Security Policy.

WiMAX Forum. (2012). Industry standards, spectrum and regulation. Retrieved from WiMAX Forum: http://www.wimaxforum.org/printpdf/1997

World Health Organization [WHO]. (2002). *Environmental health in emergencies and disasters: a practical guide*. (B. Wisner, & J. Adams, Eds.) Geneva: WHO.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. D. C. Boger
   Naval Postgraduate School
   Monterey, California